



1980

# Shear Loading of Three Orthodontic Adhesives

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## Recommended Citation

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Paul Alexandre D.F.M.L. D.E.D.L.

May

1980

[illegible]

Dedicated

To my wife Dominique for her love, understanding and  
patience, and to our children Loic, Celine, and Virginie.

## ACKNOWLEDGMENTS

I would like to express my sincere recognition to all those who have helped in making this investigation possible. I would like to extend a special thank you to the following persons:

To James Young, D.M.D., M.S., who, as my thesis advisor, gave many hours of help, advice and constructive criticism into the design and preparation of this investigation.

To James Sandrik, Ph.D., for his assistance, encouragement and guidance in the fabrication of this testing apparatus and writing of the Thesis.

To Douglas Bowman, Ph.D., the Committee member who helped prepare the statistics in my Thesis.

To my classmates, Surasing Lamsam, and Richard Lang, for their assistance in tooth sample collection.

To the following oral surgeons for their cooperation and assistance in tooth sample collection: Drs. C. Fijal J. Gianini, B. Hochstadter, P. Inhoff, H. Johnson, S. Marshall, S. Martino, J. Schemeda, Steere, V. Vivirito, and L. Wallace, and the Department of Oral Surgery of Loyola

University.

To Bernie Ciamarichello for typing the manuscript.

To Jim Cockerill for his excellent photography.

To Lewis Klapper, Chairman of the Orthodontic Department and to all the faculty members for their advices, guidance, and interests during my graduate studies.

To my best friends Jean-François Mucha and Jean-Claude Cholet, who encouraged me to enter the Loyola University.

The most profound gratitude I can express goes to my Father and my Mother for offering the greatest love and support through all my life.

I would also like to express my gratitude to the following companies for providing information, materials and supplies in this investigation:

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## VITA

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## CHAPTER I

### INTRODUCTION

Corrective orthodontic techniques use forces which are transmitted to the teeth by tying the wire to brackets or other attachments. Those in the classical technique are welded or soldered to stainless metal bands, and the metal bands are then cemented to the teeth.

Although bands have been proven mechanically satisfactory, a number of problems are inherent in their application: 1) The hygiene is difficult for the patient and some debris are trapped between the bands and the gingiva (Gibbin 1937, Noyes 1937, Graber 1972). 2) The solubility and bond strength of the cement may lead to a loose band, thus increasing the risk of decay (Shannon and Miller 1972, McCallum 1972, Lee et al 1974). 3) Long chair time for seating of bands; use of separating wires; chair time for adaptation and burnishing of bands to the teeth (conical shape, labial convexity, distal-proximal convexities) and difficulties to properly position each bracket in a full banded technique. (Lee et al. 1974)

The trend in orthodontics, as in other spheres of human activity, is to simplify technical procedures so the objective can be achieved with a minimum of effort.

The bonding of orthodontic attachments directly to etched enamel surfaces is an example of the clinical application of a simplified procedure. There has been an increasing acceptance and use of direct bonding brackets by the orthodontic specialty (Newman and Facq 1971, Retief and Sadowski 1975, Zachrisson 1977, Brown et al. 1978, Sheykholeslam and Brandt 1979, Thanos et al. 1979).

A large variety of bracket designs and adhesive bonding system are available to the clinician, making the selection of an appropriate combination difficult. Of vital importance is the ability of these systems to bond to enamel. The mechanical strength of the adhesive and the bracket material must be sufficiently great to resist the forces during the entire orthodontic treatment procedure.

A number of clinical and laboratory investigations have been undertaken to compare the retentive capacity of various direct bonding systems. These have been largely concerned with the bond strength of a single type of bracket subject to one mode of loading (Weisser 1973, Keizer et al. 1976, Low and Fraunhofer 1976, Gorelick 1977).

The considerable differences reported in the clinical trials are not surprising since direct bonding is a complicated problem and the final results are influenced by

several factors.

The purpose of this study is to measure and compare the shear strength\* of three orthodontic direct bonding adhesives: Concise (3M), Dynabond (Unitek), Endur (Ormco). No published studies have ever recorded the comparison of these three products.

Newman (1964) defined the shear strength force on an attachment (bonded to the enamel tooth surface), when a force is applied either in a mesial or distal direction, or in an incisal or gingival direction.

Bishara et al. (1975), used the term shearlike because the enamel surface of teeth is a curvature rather than a flat surface.

In this investigation the shear strength is defined as a force exerted on a bracket (bonded to the enamel tooth surface) when the applied force is parallel to the bracket-adhesive-enamel interface whatever its direction.

\*The shearing strength was the load applied to a constant bracket area of 0.0221 in.<sup>2</sup>. The term shear strength will be used instead of the term shear load in this paper.

## CHAPTER II

### REVIEW OF LITERATURE

#### ADHESION:

Few aspects of orthodontics are currently receiving as much attention as the direct bonding of orthodontic brackets to the enamel surface of the teeth.

According to Phillips (1973a), adhesion is defined as the molecular attraction between the surfaces of bodies in contact, or the attraction between molecules at an interface. This force is called adhesion when unlike molecules are attracted, and cohesion when molecules of the same kind are attracted.

The material producing adhesion is called adhesive and that to which it is applied, the adherent. The interface is the area between the interacting substances.

The molecular forces involved in adhesion are divided into chemical (primary attractive forces), and physical attractive forces (secondary attractive forces). The physical forces of attraction result in the adsorption of the adhesive on the adherent: they put the adhesive

molecules in close contact with the adherent surface.

Although weaker than the chemical attractive forces, the physical forces of attraction are strong enough to produce good adhesion, provided that adequate intermolecular contact is achieved at the interface.

Adhesion is dependent on intimate interfacial contact and exists only if the molecular forces of attraction do not operate beyond two or three angström units. If solid surfaces are naturally smooth on an atomic scale, they will adhere spontaneously when brought together. The molecular forces of attraction will operate all along the interface and a strong bond will result (Buonocore 1963, Retief 1973a ).

In practice, it is impossible to obtain such atomically smooth surfaces. If rough surfaces are brought into contact, the molecular forces of attraction will operate only where the tips of the asperities on the surfaces meet. These are so widely spaced, that the attractive forces are small, and poor adhesion will result.

To obtain adhesion between rough surfaces, a liquid adhesive is introduced between the surfaces. The function of the adhesive is to flow into the irregularities of the surfaces to be bonded, thereby establishing close contact with them. For practical reasons, it is not only necessary to obtain molecular closeness but also to maintain it. For this reason, a liquid adhesive that solidifies is used.

This is achieved by the evaporation of a volatile component or by polymerization or cross-linking of the adhesive molecules by means of heat, catalysts or reactive hardeners.

To produce adequate adhesion, the liquid adhesive must flow easily over the entire surface, thereby ensuring the wetting of the adherent surface. The extent to which an adhesive will wet a surface depends on the viscosity of the adhesive, the shape of the irregularities on the surface of the adherent, and the contact angle at which the adhesive meets the surface of the adherent (DeBruyne 1962, Phillips 1973a). Wetting is therefore a manifestation of the attractive forces between the molecules of the adhesive and the adherent.

#### DENTAL MATERIAL:

A satisfactory adhesive dental material must take into account the physical and chemical properties of the dental hard tissues to which it must adhere. The properties of enamel will determine the adhesive potential of the tooth surfaces. The enamel of the tooth is completely formed when the tooth erupts in the mouth. The enamel therefore does not have the property of self repair and its morphology is only altered through mastication, chemical action of fluids and bacterial action, and is submitted to the changes of the temperature. According to Sicher et al. (1972), Permar et al. (1977), the composition of enamel is 96 per cent

by weight in inorganic substance, and four per cent by weight in organic substance and water.

Mjör and Pindbord (1973), mentioned one - two per cent by weight in organic material and three - four per cent by weight in water. The inorganic portion consists of hydroxyapatite crystal with a central core of hydroxyapatite  $\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2$ . The entire crown of a newly erupted tooth is covered with a thin membrane often called the dental cuticle. It is believed to be a product of cellular activity in the late stages of enamel formation. It is generally accepted that the developmental structures covering the tooth surface are lost soon after eruption. Thus, the pellicle that is found on the tooth surface, under ordinary condition is of a salivary origin (Leach 1967).

In the initial stages, the formation of the tooth pellicle involves a selective absorption process of salivary proteins onto the surface of the tooth enamel. As the pellicle ages, it appears that its composition changes in an undetermined manner that probably involves contributions of microbial origin (Armstrong and Hayward 1968). It had been shown that the salivary pellicle is permselective and plays a role in transport of ions between the oral cavity and the tooth enamel surface (Moreno 1975). This layer of absorbed ions is surrounded by a superficial hydration layer, strongly bound to the hydroxyapatite.(Jenkins 1978a).

The relatively small organic component plays a very



important part in determining adhesion to tooth structure, by modifying the conditions of wettability of the enamel surface. Eastoe (1966), expressed the opinion that the organic component is present either as continuous gel or a viscous sol.

The enamel surface is covered with a water layer that reduces the surface energy and thus prevents the wetting of the adhesive. So, for proper wetting of the enamel surface, the adhesive must displace this water layer or react with it, and the surface tension of the unpolymerized adhesive must be lower than the critical tension of wetting of the tooth structure. It is therefore extremely difficult to obtain adhesion to low energy tooth surface (Phillips 1973a).

#### PRETREATMENT OF ENAMEL:

In 1955, Buonocore published his description of "a simple method of increasing the adhesion of acrylic filling materials to enamel surfaces". He demonstrated markedly improved retention of methyl methacrylate resins to enamel after a 30 second application of 85 per cent orthophosphoric acid. He concluded that increased adhesion was due to several factors: 1) an increase in the surface area produced by the acid etch, 2) an exposed organic framework, 3) removal of an inert enamel layer, exposing a fresh reactive surface, 4) presence on the enamel surface

of an adsorbed layer of highly polar phosphate groups (from the phosphoric acid).

All these factors contribute to the wettability of the enamel surface. During the past 25 years, major developments occurred and made the bonding of attachments to teeth feasible.

In 1960, Swanson and Beck demonstrated that etching enamel for receiving cyanoacrylate provides better results than untreated enamel, provided the surface is clean and dry.

In 1965, Newman was the first to use the acid etch technique for bonding orthodontic brackets to the teeth with an epoxy derived resin. Many studies have been made to improve the bonding system (Newman and Facq 1971, Miura 1972, Silverman et al. 1972, Mitchem et al. 1974, Leinfelder et al. 1975, Retief et al. 1975, Silverstone 1975, Moser et al. 1976, Reynolds et al. 1976b, Jordan et al. 1977, Gorelick 1977, Zachrisson 1977, Brown et al. 1978, Sheykholeslam et al 1979, Thanos et al 1979). The advantages of preconditioning the enamel surfaces have been studied by many authors:

In 1966, Newman and Sharpe concluded that the acid pretreatment converts the low energy, hydrophobic enamel surface into a high energy, hydrophilic surface, showing increased surface tension and wettability. By etching the surface of the enamel with acid, a much stronger adhesion is obtained (Buonocore 1955, Gwinnett and Matsui 1967,

Mitchell 1967, Buonocore et. al. 1968, Gwinnet 1971a, Brauer et al 1972).

In 1974, Silverstone showed that the acid solution produced changes to the enamel surfaces in two distinct ways. The first stage was the removal of a shallow layer of enamel by etching. In this manner, plaque surface and subsurface cuticles are effectively removed from the site to be bonded. This was followed by the second stage on which the remaining enamel surface is rendered porous by the acid solution. It is in this porous region that the resin is able to penetrate and to bond with the enamel (Silverstone 1975).

In 1967, Gwinnett and Matsui conducted experiments on eight different materials after etching the enamel tooth surface. Optical and electron microscpcopy studies revealed the formation of "tags"-extensions of the materials ( 10 - 25 microns) into the enamel surface. Each tag or filament was continuous with its neighbor by means of a relatively translucent sheet to form a continuous structure. No tags were observed on untreated areas or sites where "prismless" enamel existed. Tag lengths varied from material to material, from one tooth to another, and from one site to another within the same experimental area.

In 1968, Buonocore et al. investigated the prismlike tags previously reported by Gwinnett and Matsui (1967). Adhesion of various resins to enamel surface was enhanced by

etching. Acid etching of human enamel creates microporosities from 10 up to 50 microns in depth by the removal of inorganic enamel structure (Gwinnett and Matsui 1967, Buonocore, Matsui, Gwinnett 1968, Gwinnett 1971a, Hoffman 1972, Retief 1973b, Silverstone 1973, Fitzpatrick and Way 1977).

Gwinnett (1971a), Johnson et al (1971), Hoffman (1972), Retief (1973b), showed that removal of the enamel occurs at either the prism center or the periphery. Surface treatment with phosphoric acid exposes the enamel prisms and produces the characteristic "prism end" structure. At higher magnifications a typical honeycomb appearance is observed which clearly demonstrates the preferential etching action of the acid. (Retief 1973a)

Poole and Johnson (1967), using a scanning electron microscope (S.E.M.) examined enamel surfaces etched with various agents: formic, lactic and hydrochloric acids, as well as ethylene diamine tetra-acetic acid (E.D.T.A.). The acids appeared to dissolve the core of the prism, while the E.D.T.A. dissolved the periphery, leaving the central portion intact.

Hoffman and his associates (1969), confirmed the work of Poole and Johnson (1967): acid caused demineralization of the enamel prism cores while E.D.T.A. removed the periphery.

### THE ETCHING SOLUTION:

While most investigators now advocate an acid pre-treatment prior to bonding an adhesive to enamel, the etchant and procedure may vary. These include: 1) phosphoric acid incorporated in a zinc phosphate cement liquid or silicate cement liquid (Gwinnett and Matsui 1967), 2) a specified concentration of phosphoric acid usually 50 - 85 per cent by volume (Buonocore 1955, Retief and Dreyer 1967, Retief, Dreyer, Gavron 1970, Gwinnett 1971b, Laswell, Welk, Regenos 1971, Lee, Cupples, Schubert, Swartz 1971a, Miura et al 1971, Sharp and Grenoble 1971, Retief 1973b), 3) an attenuated solution of 50 per cent phosphoric acid with seven per cent by weight zinc oxide (Gwinnett and Buonocore 1965, Cuetto and Buonocore 1967, Buonocore et al. 1968, Buonocore 1970, Sheykholeslam and Buonocore 1972, Cohl et al. 1972, Brauer et al. 1972), 4) 50 per cent solution of citric acid (Lee et al. 1971a, Lee and Schwartz 1971b), 5) in 1968, Mulholland and Deshazer studied the effect of acidic pretreatment to the enamel by the use of acid hydrofluoric, acid hydrochloric, acid phosphoric and acid aspartic, 6) 50 per cent orthophosphoric acid with five per cent zinc oxide, plus one per cent sodium monofluorophosphate for two minutes (Newman and Facq 1971), 7) one per cent orthophosphoric acid for five minutes on bond strength of zinc carboxylate cement (Mizrahi and Smith 1969b), 8) 40 per cent orthophosphoric

acid (Lenz and Mühleman 1963a).

Controversies had arisen about the concentration of the etching acid. But the most consistently uniform and suitable etch was obtained by application of orthophosphoric acid ranging within the 30 to 40 per cent. These findings have been confirmed by Weisser (1973), Retief (1973a), and Silverstone (1975). The strength of the bond is enhanced when a 37 per cent unbuffered orthophosphoric acid solution is used for 60 seconds as an etching agent (Silverstone 1974). This solution produced the most consistent and evenly distributed etch on a single enamel surface (Silverstone 1975). The etchant can be obtained either in solution or in gel form. K. Moin and Dogon (1977), reported that the etching produced by gels with higher acid concentration was in general better than those produced by lower acid concentration. Acid gel can be readily applied to localized small areas on the crown of teeth, but they do not produce a uniform homogeneous etched surface. Furthermore, gels are more difficult to remove from tooth surfaces since microscopic remnants of gel are found even after washing with a liberal spray of water on etched enamel surfaces. The results of bonding attachments to teeth after etching with gels are therefore unreliable (Moin and Dogon 1977).

Pretreating the enamel surface with an acid is a necessary step in achieving satisfactory adhesion. When

surface debris is removed, a more wettable surface is produced, and the effective surface area available for bonding is increased. Retention is improved due to the mechanical interlocking that takes place between the demineralized portion of the enamel prism and the adhesive.

#### FACTORS AFFECTING THE ETCHING PROCESS:

Various factors can affect the etching process: a) Enamel with a high fluoride content is more resistant to acid and consequently etching will be more difficult to set up (Lee et al. 1972); b) The chief factor of a successful etching is the duration of etching time which is normally reported as one minute (Newman 1973, Silverstone 1975); c) Wickwire and Rentz (1973), however, found that four minutes is optimal, while etching for six minutes results in disruption of the enamel structure. Excessive etching reduces the retention of sealant by the removal of more surface, thereby, limiting the penetration of the sealant into the etched pores (Moin and Dogon 1977); d) Variations in acid etching are found not only between different teeth, but also on the same tooth (Brännström and Nordenvall 1977). This means that the retention of resins also varies; e) Drying agents for bonding material are not recommended as they leave undesirable residues (Moin and Dogon 1977); f) It is essential that once after etching has started, the patient should not be allowed to rinse

because contact of salivary proteins and debris on the etched surface will interfere with successful bonding (Moreno 1975). If the etched surface is accidentally contaminated, it should be re-etched for approximately 30 to 60 seconds (Smith 1975, Moin and Dogon 1977).

Young et al. (1975), studied the effect of moisture at the bond surface and concluded that there was no difference between a normal dry condition using a five second drying period, with five liters per minute and an extra drying period of 60 seconds. However, under wet condition, the bond strength was drastically reduced. Moisture within the oral cavity cannot be eliminated. Retief (1970b) observed that even if a vacuum pump was applied to the mouth, the teeth could not be dried thoroughly at room temperature. Drying a tooth cannot be maintained. Bergman (1963), demonstrated that fluid flows continually from the pulp to the enamel surface. This flow is spontaneous and does not require a rise in intrapulpal pressure. Also, Linden in 1968, showed that fluid flow to the enamel surface does decrease as permanent teeth become older. The adhesive must contend with at least a monolayer of water at the adhesive enamel interface. The adhesive, therefore, would have to either compete with the water or "bond" to it.



### REMINERALIZATION:

It is difficult clinically to etch only that portion of the tooth surface to be bonded, therefore, the entire labial or buccal surface is routinely etched. Controversies exist as to what happens to the etched surface that is not protected by a covering of resin.

Buonocore, in 1955, felt that acid treatments were clinically safe. Newman (1965), answered the criticisms of etching, by noting that dental cements contained 35 - 55 per cent phosphoric acid. Also, the cements utilized in band cementation may have a pH of 1.6; this may last for as long as 15 - 45 minutes after cementation.

Newman and Sharpe (1966), were able to retrieve the surface existing before phosphoric acid treatment, by pumicing. The etched hydrophilic surface became hydrophobic.

In 1971, Newman and Facq used a scanning electron microscope to study the effects of adhesive systems on tooth surfaces. They found that an etched enamel surface can be restored to its original appearance by pumicing.

Retief (1973b), showed scanning electron micrographs to demonstrate the in vivo recovery of etched enamel. After an etched tooth was exposed to the oral environments for two weeks, recovery was almost complete.

Fitzpatrick et al. (1977) tried to prove the wearing of the etched surface by the normal attrition. Retief, Dreyer, and Gavron (1970), reported that the etched enamel

regained a normal appearance within a few days. They felt that abrasion or remineralization may have caused the normal appearance.

Lenz and Mühleman (1963a - 1963b) noted that the pattern of prism endings characteristic of an etched surface disappeared in samples exposed to the oral environment, within a period of two days. Mühleman et al. (1964), Johanson (1965), Albert and Grenoble (1971), Moreno (1975), noted the same changes, but within a shorter period of time. Enamel exposed to the oral environment was able to redeposit calcium phosphate from the saliva from one hour to two days. After a few days, the etched enamel was normal.

But all of them concluded that the surface was rendered smooth by deposition of a salivary pellicle rather than actual remineralization.

Newman (1969) utilized interferometer measurements to show a significant reduction in the maximum peak to-valley heights due to acid pretreatment. He confirmed the view of Lenz and Mühleman (1963a, 1963b) and others: etching had been eliminated by a pellicle of salivary origin.

Wei (1970), studied enamel remineralization with an electron microprobe. He concluded that acid etching was confined to the first nine - ten microns from the enamel surface, and calcium and phosphorous were lost during the etching process. When a calcifying solution was applied to the treated enamel the mineral content was restored:

remineralization had taken place.

Sealing the entire facial or labial surface of the enamel protects the tooth against decalcification from plaque and debris collecting around the bracket (Tillery et al. 1979). The ability of the adhesive to penetrate into the enamel and envelop or encapsulate the crystallite components seemingly promotes resistance to demineralization. The bonding resin flows into the microscopic crevices, creating a mechanical interlock that secures the bond. When the bonding agent invades the micropores, extensions are produced that are referred to as resin-tags. The protection imparted by such penetration was demonstrated, in vitro, by placing teeth, from which the bulk material was cleaved away, into an acid buffer system. The untreated surface readily demineralized while the surface protected by the adhesive remained unaffected (Gwinnett and Matsui 1967).

#### PROPERTIES REQUIRED FOR AN ADHESIVE:

A variety of materials with adhesive potential was studied in the past. Investigators tried to produce an ideal dental adhesive, useful in restorative dentistry, preventive dentistry (sealants) and orthodontics. However, an adhesive material that is intended for use in the oral cavity must withstand many insults: continual moisture and

high humidity, pH fluctuations, temperature extremes, variable stresses and possible bacterial attack.

Like stated previously, moisture within the oral cavity cannot be eliminated, and the fluid flowing continually from the pulp to the enamel surface prevents the tooth to be dried.

Fluctuations in pH are a second factor that an adhesive must be able to withstand. Newman (1964), reports that while the pH of saliva may range from 6.8 - 7.2, that of fluid taken into the mouth may vary greatly.

Temperature extremes are a third insult to which adhesives are exposed. While the oral temperature (98.6 degrees F.) may tend to buffer the temperature changes of ingested foods and liquids, these may however produce sudden and instantaneous temperature extremes (ice cream (35 degrees F.) and hot tea (145 degrees F.)).

Retief (1970b) emphasized that the instantaneous changes in temperature may be of significance if there is a pronounced difference in the coefficient of thermal expansion of tooth and adhesive.

A number of studies have been made to determine the biting force. Mizrahi et al. (1971) stated that the order of force exerted by the jaws during mastication is 12 kgs. for a molar.

The biting forces among young people eating "civilized" food, have been found to be about 190 pounds for

molars. The first molar exerts the greatest biting force, the other molars slightly less, but the premolars and incisors are capable of developing forces from 20 pounds up to about one third of the force produced by the molars (Jenkins 1978b).

One other study reported an average value of 170 pounds, (77 kgs.). However, it varies markedly from one area of the mouth to another, and from one individual to another. In the molar region, it may range from 41 to 91 kgs. (90 to 200 pounds), in the premolars area from 23 to 46 kgs. (50 to 100 pounds), 14 to 34 kgs. (30 to 75 pounds) on cuspids, and nine to 25 kgs. (20 to 55 pounds) on incisors. Undoubtedly, the nearly instantaneous forces incurred during mastication are much higher than those measured in these studies (Philips 1973b). Newman (1964 - 1965) believes that orthodontic forces liberated by orthodontic archwires and rubber elastics are from one p.s.i. to 140 - 200 p.s.i.

These masticatory stresses involve combinations of tensile, shear, compressive and torquing modes. Masticatory forces alone or combined with forces from orthodontic appliance may exceed these values.

Finally, adhesives are exposed to bacterial and hydrolytic attack.

#### THE COMPOSITES:

The ideal adhesive material has not been developed;

however, various organic polymers are available that fulfill many of the requirements seen previously: these include acrylics, epoxides, polyacrylates (polycarboxylate cements), cyanocrylates, polyurethane, and composites of acrylics and epoxides. Because this study investigated the composites, only some of the authors who researched on these materials were reviewed.

Bowen in 1962, synthesized a molecule of resin. The base resin consists of the reaction product of an epoxy resin (bisphenol A) and of an acrylic (glycidyl methacrylate) (Ill. 1). The Bis-GMA molecule may be synthesized in a number of ways. One way is to react the glycidal ether of bisphenol A and methacrylic acid. A second way is to react the bisphenol A and glycidyl methacrylate (Phillips 1975).

The term composite indicates the presence of a large percentage of reinforcing filler in the form of glass, quartz or pure silica.

The physical properties of the resin matrix are significantly improved by the incorporation of the inorganic filler (Phillips 1970). By the incorporation of an organo functional silane coupling agent, effective adhesive bonding of the filler particles to the polymerizing resin phase is obtained (Bowen 1962 - Bowen 1963).

Composite resins are in general more rigid, less abrasive and more stable than unfilled resins. Water

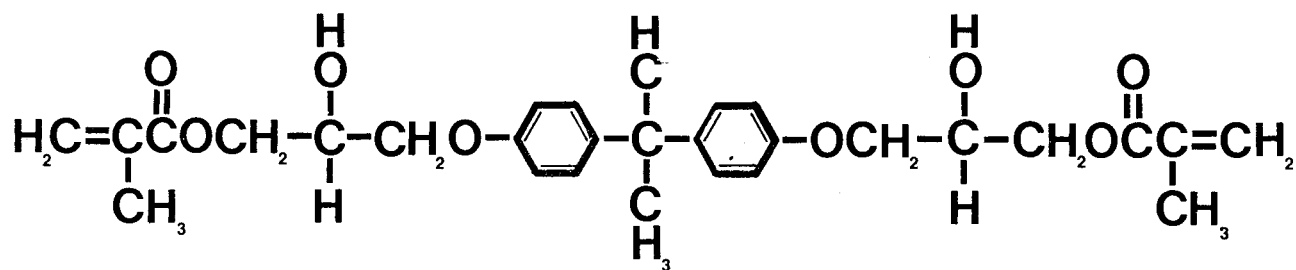


Illustration I: Linear formula of a Bis-GMA molecule.

sorption is clinically insignificant, polymerization shrinkage is low and the working and setting times are shorter (Phillips 1973b).

Currently available resins for orthodontic use are based on Bowen's Bis GMA resin, modified by suitable viscosities for optimal penetration into the etched enamel surfaces. These resins apparently achieved the required strength to withstand the forces applied to the brackets and the abrasive forces of routine tooth brushing.

Bis GMA resin itself has a relatively high viscosity which makes it unsuitable for the addition of fillers and for penetration into etched enamel. Diluent resins of the aliphatic diacrylate type are widely used to reduce this viscosity, and to make the resin system suitable for use in the acid etch technique (Dogon 1975).

Specimens coated with resins of 320 centipoises demonstrated markedly increased tag length which almost entirely filled the space within the etched enamel. This was more noticeable in the resins of relatively low viscosity (236 and 185 centipoises) (Dogon 1975).

Controversy exists as to the need for an intermediary resin system of low viscosity to penetrate the acid etched surface prior to the placement of restorative resins.



BRACKETS:

Attachments or brackets for orthodontic direct bonding systems are made of stainless steel or of a resin product. Metal brackets have been used and reported by many investigators (Sadler 1965, Mitchell 1967, Retief and Dreyer 1967, Mulholland and Deshazer 1968, Mizrahi and Smith 1969a, Retief, Dreyer, Gavron 1970, Mizrahi and Smith 1971, Mizrahi 1972, Low and Fraunhofer 1976, Moin and Dogon 1978, Thanos, Munholland, Caputo 1979).

While these brackets are strong, they must be constructed so as to mechanically lock into the adhesive since no chemical bonding takes place between the metal bracket and adhesive.

Thanos et al. (1979) investigated the bond strength of mesh base and metal base brackets, for different adhesive systems. The bond strengths were determined by means of tension, shear, and torsion tests on an Instron machine. Screens having mesh size of 50 and 60 (number of openings per linear inch) were used. The 50 mesh screen had a wire diameter of 0.009 inch and an aperture of 0.011 inch. The corresponding dimensions for the 60 mesh screen are 0.0075 inch and 0.009 inch. The metal brackets were spot welded on the mesh screens in five places (four corners and center). The data were statistically analyzed and the following conclusions were drawn: mesh base brackets were more retentive than the metal base brackets in tension, while

metal-base brackets were more retentive in shear.

Low and Fraunhofer (1976) stated: that weakness in the attachment is not at the tooth adhesive interface, but at the mesh adhesive junction; that mesh base bracket provides superior bond strength when compared to perforated metal base bracket.

The same authors and Reynolds and Fraunhofer (1976a) claimed that when metal attachments are used for direct bonding, the use of coarser mesh gauzes is advised for mechanical retention, i.e., possessing a wire diameter of not less than 150 microns (with a matching aperture of approximately 250 microns). This means the standard mesh number should be 50 or 60 (British standard size).

Moin and Dogon, in 1978, stated that mesh pads covered with solid metal base provide better retention than the perforated bracket.

Moin and Dogon (1977) used Concise enamel bond system with metal mesh bracket and found the bond strength doubled the value compared to the Concise used with metal perforated brackets. The mean value of shear strength was between 30 to 35 pounds with perforated brackets and between 60 and 70 pounds by using mesh brackets.

Since adhesives do not bond to stainless steel brackets, additional features have been suggested.

Dietz (1972) recommended an alcohol wipe to eliminate possible contaminants. Touching the bracket

without the aid of an instrument was contra-indicated.

Low and Fraunhofer (1976) stated that each bracket should be countered to fit the buccal surface of the tooth as closely as possible and cleaned with chloroform before use. Tweezers should be used to avoid any contact with fingers.

The thickness of the resin between the mesh and the tooth surface should be minimized by a careful adaptation of the bracket pad to the crown surface on the dental cast prior to bonding (Moin and Dogon 1978). The thickness of the adhesive layer is an important factor in obtaining and maintaining adhesion (Buonocore 1963, Retief 1970a). As the adhesive increases in thickness, the joint strength decreases. Buonocore (1963) and Retief (1970a) propose a number of reasons: a thin layer may produce fewer imperfections in the joint; a thick layer may deform and fracture readily; and a thin layer will produce less shrinkage during polymerization.

#### TESTING PROCEDURES:

Testing adhesive joints has been an area of concern for dental investigators. To date, however, standard testing procedures or guidelines have not been established. Almost every investigation examines adhesion differently.

Buonocore (1955) used his thumbnail while attempting to remove bonded acrylic beads. Swartz and Phillips (1955)

used a Tinius Olsen testing machine to examine the adhesiveness of an acrylic resin and zinc phosphate cement to enamel. Swanson and Beck (1960) used a simple tensile device for the in vitro portion of their investigation. It consisted of a heavy laboratory stand with adjustable clamps so that a perpendicular force would be applied to the bonded surfaces. A platform was attached to the free end of the chain, and weights were added in 100 gm. increments. The breaking point was recorded in kilograms. Bernstein (1965) used both a tension meter and digital pressure to dislodge his samples. Newman (1965) and Newman and his associates (1968), used a Chatillon Model DTC Universal Tester. A tensile force at the rate of one pound per second was applied until the joint failed. Retief, Dreyer and Gavron (1970), in order to test tensile stresses, imbedded wire loop into their bonded epoxy samples. Twenty four hours later, a container was fixed to the wire loop; the container was gradually filled with water until the bond broke. The weight of the container and its content were recorded: bond strength was expressed in pounds per square inch. Keizer et al., in 1976, measured the shear strength of ten resin systems, by means of Zwick tensile testing machine.

Recently, investigators have begun using an Instron Testing machine to study bond strengths (Mizrahi and Smith 1969a, Crabb and Wilson 1971, Laswell et al. 1971, Cohl et al. 1972, Rensch 1973, Retief 1975, Johnson et al. 1976, Low

et al. 1976, Reynolds et al. 1976a, Moin and Dogon 1978, Moser et al. 1979, Thanos et al. 1979).

Specimens are mounted on a cross head that moves at a constant rate preset by the investigator. Tensile, shear and modified tensile and shear stresses can be applied to a sample. While this procedure is precise, strain rates may vary from study to study. Some numbers will be given to get an idea of the values that could be expected to be found in this investigation, although all resins tested were different and comparisons difficult.

Some authors used animal teeth. Keizer et. al. (1976) used freshly extracted bovine incisors with relatively flat surfaces. Then, he ground them until a flat, smooth enamel surface was obtained. Johnson et al. (1976) used bovine teeth too, but the proximal surfaces of each tooth were sliced perpendicular to the incisal edge with a diamond disc to ensure accuracy of later bracket placement and fitting in the Instron Machine. Reynolds and Fraunhofer (1976a), Moin et al. (1978) and Moser et al. (1979) used premolars extracted for orthodontic purposes. Thanos et al. (1979) used anterior teeth freshly extracted.

Except for some teeth that have been flattened for the experimental purpose, usually they have been prepared according to the specific instructions of each manufacturers i.e., pumiced, etched, dried, and then bonded. However, the conditions of storage before and after bonding are different

from one study to another.

Thanos (1979) stored the teeth in a saline solution, and mounted them in an improved dental stone block. Johnson et al. (1976) used a 30 per cent saline solution before and after bonding. Reynolds et al. (1976a) stored teeth in water before and after bonding. Nagel (1973) used distilled water before and after bonding. Moser et al. (1979) stored the premolars in 10 per cent formalin solution at room temperature. Then, after cleaning, he stored them in artificial saliva at 37 degrees before and after bonding the brackets. Moin and Dogon (1978), in order to subject the teeth to temperature changes, submitted all the teeth in a thermocycling unit for 500 cycles. A cycle consisted of one minute immersion in one degree C. distilled water, followed by one minute immersion in 60 degrees C. distilled water, with a 45 second interval between the hot and cold immersions.

Most investigators preset their testing apparatus at about the same speed: Johnson et al. (1976), Moser et al. (1979), Thanos et al. (1979), Retief (1975), put the crosshead speed at .02 inch per minute, and the chart speed at one inch per minute. Moin et al. (1978), set the speed faster: .2 inch per minute and the chart speed at two inches.

All used a shear loading mode. But the means used to apply this load vary. Very often, a special harness was

fabricated for attaching the bonded sample fixed in the crosshead grip, to the fixed grip of the instrument.

Moin and Dogon (1978), used a Rocky Mountain Truchrome Orthodontic wire, 0.018 inch in diameter: the one was looped around the bracket wings, and the two free ends of the wire were secured in the stationary lower pneumatic action clamp of the Instron. Since the upper pneumatic clamp was secured to a two axis rotational swivel, the bracket self aligned with the plane of the wire loop as the load increased. Thus, at ultimate shear load, the vector was essentially parallel to the surface of the tooth.

Moser et. al. (1979) used an orthodontic wire harness and the load was applied parallel to the bracket enamel surface. Thanos et al. (1979) used a rigid rod to achieve the shear mode load in their investigation, with the teeth mounted in an improved dental stone block. Johnson et al. (1976) used a special harness consisted of a rectangular loop of 0.040 inch round cobalt-chromium wire measuring one inch by one-quarter inch. A three inch extension of 0.040 inch cobalt-chromium wire was soldered to the middle of the upper end of the loop. The lower end of the loop was reduced rectangularly to 0.022 inch by 0.040 inch with a rubber disc for insertion under the gingival ligature tying space of the edgewise bracket. The harness was hung from the upper fixed grip and the lower edge of the loop was engaged in the gingival ligature space of the edgewise

bracket. A shear test was performed on each sample with the pull of the moving crosshead parallel to the bracket enamel interface.

The tests are performed at different periods: Johnson et al. (1976) tested the samples at the 24th hour, one month and three months; Nagel (1973), after one day and 30 days; Keizer et al. (1976) after one hour; Thanos et al. (1979) after 30 minutes after bonding; Moser et al. (1979) after seven days and one month.

#### STATISTICAL DESIGNS:

The results vary with the different materials tested. All of them were statistically analyzed. Thanos et al. (1979) evaluated the data via a two-way analysis of variance, Duncan's New Multiple Range test, and multiple t-test, using 10 teeth per sample. Moser et al. (1979) used 10 teeth per sample, and all mean bond strength were compared with a pair wise t-test. Johnson et al. (1976) used 10 teeth per sample. The mean shear strength of each direct bonding material at each time interval, was compared statistically to the mean shear strength of each of the materials at each time interval with a matched t-test. The same test was used to determine whether there had been a significant change in mean shear strength from start to finish. Nagel (1973) used a two by ten factorial analysis of variance. While there was significant difference among



the means of all materials ( $p < 0.001$ ), a Tukey's test comparing individual means yielded no differences among the orthodontic direct bonding systems ( $p > 0.05$ ).

### EXPERIMENTAL RESULTS:

The results themselves are different mainly because they are performed on different material, and also because experimental designs are different.

Moser et al. (1979) used four resins: two based upon the P.M.M.A. system (polymethyl methacrylate): Orthomite II's and Directon, and two based upon the Bis GMA system: Nuvaseal (unfilled resin) - Nuvatach (filled resin) and Genie. After seven days storage in Ringer's solution, Directon and Genie showed significantly greater shear bond strength than the Nuvaseal-Nuvatach system, while Orthomite II's showed intermediate strength. Directon and Orthomite II's showed a significant decrease in mean shear bond strength from seven to 30 days, while Genie maintained its initial good strength through that period.

The values in  $\text{MN/m}^2$  were the following:

	7 days	30 days
Bis GMA system	11.8 - 14	8.5 - 12.5
PMMA system	12.8 - 14.6	7.5 - 8.7

Johnson et al. (1976) investigated seven adhesives: Nuvatach showed a significantly better mean shear strength (30.17 pounds) than any other material at each test

interval; Orthomite II's (21.55 pounds), Directon (20.06 pounds), Unitek adhesive (16.10 pounds) were grouped in the medium high classification; Orobond (26.15 pounds) and Genie (10.87 pounds) were grouped in the medium low classification; Strata Dent (0.42 pound) showed mean shear strength that was significantly lower than any other material at all time intervals. At five per cent level of significance, Nuvatach (31.87 pounds) and Genie (9.70 pounds) did not show any difference in the mean shear strength, Orthomite II's (16.94 pounds), Directon (12.57 pounds), Unitek adhesive (13.68 pounds), Orobond (8.61 pounds) showed a decrease in mean shear strength: However, Strata dent (2.86 pounds) showed an increase in the mean shear strength.

Thanos et al. (1979), investigated five adhesive systems and brackets with two different sizes of screens having mesh sizes of 50 and 60. The mesh base brackets were more retentive than the metal base brackets in tension, while metal base brackets were more retentive in shear loading mode. For the metal base brackets, Bond Eze was the most retentive material, Adaptic and Orthomite followed narrowly behind, and Genie was the least retentive. For the mesh base brackets in tension and shear, Bond Eze, Adaptic and Solo Tach were the most retentive materials when used with the 60 mesh base and Genie was the least retentive. These findings are substantiated by the following values in shear loading mode: Adaptic - 27.40 pounds; Bond Eze-32.45

pounds; Genie-20.35 pounds; Orthomite-27.42 pounds; Solo Tach-25.52 pounds.

Keizer et al. (1976) investigated a number of resin systems, all based on a bisphenol GMA type of resin, commercially available: Directon, "lightwire" adhesive, or synthesized adhesives. The maximum average bond strength to enamel was 121 kg per square centimeter, while the maximum adhesion to the bracket material was 53 kgs. per square centimeter. Consequently, the attachment of the adhesive to the bracket material is the key in direct bonding procedure.

Moin and Dogon (1978), used different combinations of the filled and unfilled resins of the Concise bonding system. In group A, brackets were bonded by mixing equal amount (by volume) of catalyst paste and universal liquid. In group B, the etched surfaces were first sealed with Enamel bond (unfilled resin) and then the brackets were bonded to the tooth with 70 per cent filled Concise (Concise orthodontic System). In group C, the brackets were bonded by a mixture of the Universal and catalyst liquid of Enamel bond (unfilled resin). In group D, Concise restorative (78 per cent filled) was used for bonding the brackets. No statistically significant differences in the mean shearing strength of the bonds were observed between groups A (54 pounds) and B (63 pounds). Group C (35 pounds) showed a lower mean value than groups A, B, D (54.6 pounds) ( $p < 0.01$ ). Variance in group D was significantly greater than in

the other groups ( $p < .05$ ). The mean shearing strength of adhesive in group A (54 pounds) and D (54.6 pounds) corresponded closely, but the standard deviation of the distribution of values in group D was nearly five times greater than in group A. The mean shearing strength of group C was the lowest (35 pounds), and the coefficient of variation was greater than in group A or B.

The Concise Enamel bond system has great flexibility in its use for orthodontic purposes. Its strength, viscosity, and setting time can all be adjusted to the operator's needs (Zachrisson 1975 - 1976). The chemical properties of the Concise Enamel bond composite are practically identical to those of the Nuva system (Mitchem and Turner 1974, Silverstone 1975). However, the sealant and the adhesive pastes are polymerized chemically rather than with ultra violet light, which makes the material easier and quicker to work with.

#### MICROSCOPIC OBSERVATION:

During the development and subsequent laboratory evaluation of dental material, the resin/etched enamel bond strength is often determined by means of tensile loading tests.

The site of failure is recorded as occurring within the test material: partly within the material and at the interface; at the resin enamel interface; within the enamel;

or in a combination of these sites. An examination under high magnification of the fractured surfaces, shows a better understanding of the mechanism of fracture.

Moser et al. (1979) after testing, examined the teeth under .12X magnification to determine grossly the type of fracture (cohesive in the cement, adhesive at either of the two interfaces, or a combination of adhesive and cohesive failure). Selected test specimens were then stored in tap water at room temperature until scanning electron microscopic (S.E.M.) characterization was performed. S.E.M. analysis revealed that most bonds which appeared to be of an adhesive nature when viewed under low magnification, actually turned out to have a cohesive component when viewed under higher magnification.

Thanos et al. (1979) selected post test specimens, from each experimental group, studied them with the scanning electron microscope. For all test modes, the most common type of failure (45.8 per cent) occurred at the tooth adhesive interface. The second type of failure (26.7 per cent) was at the adhesive bracket interface. A cohesive-adhesive type of failure (17.1 per cent), where part of the adhesive remained on the tooth and part on the bracket, was also observed.

Retief (1975), investigated 105 experimental bonds. The surfaces exposed after the failure of a test specimen were examined with a magnifying glass (8X), and the sites of

failure recorded. One specimen broke within the enamel, 24 partly in the adhesive and at the interface and 80 failed at the interface. The interfacial fracture sites were examined. The interface is defined as the zone between the interacting substances. It became apparent from the surface appearances of the enamel and resin aspects of an interfacial fracture site, that failure at the interface cannot be regarded as a clean interfacial break. Spicules of adhesive which had penetrated the etched enamel surface during the preparation of the experimental bonds, fractured during the tensile loading tests and remained embedded in the enamel surface. This should result in a smoother surface profile. Similarly spicules of etched enamel may fracture during the loading tests and are retained within the resin (Ill. 2, 3). It was concluded that the sites of failure of experimental bonds can only be classified after examination of fractured surfaces at high magnification. Scanning electron microscopy is an ideal means of evaluating these criteria. Interfacial failure between a resin system and etched enamel should not be classified as such, but rather as fracture occurring both within the resin and the enamel.

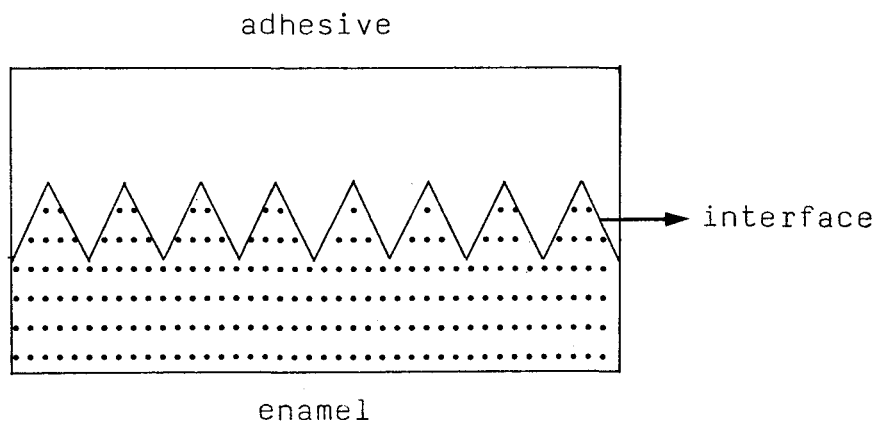


Illustration 2: Diagrammatic presentation of the interface of a bond on etched enamel.

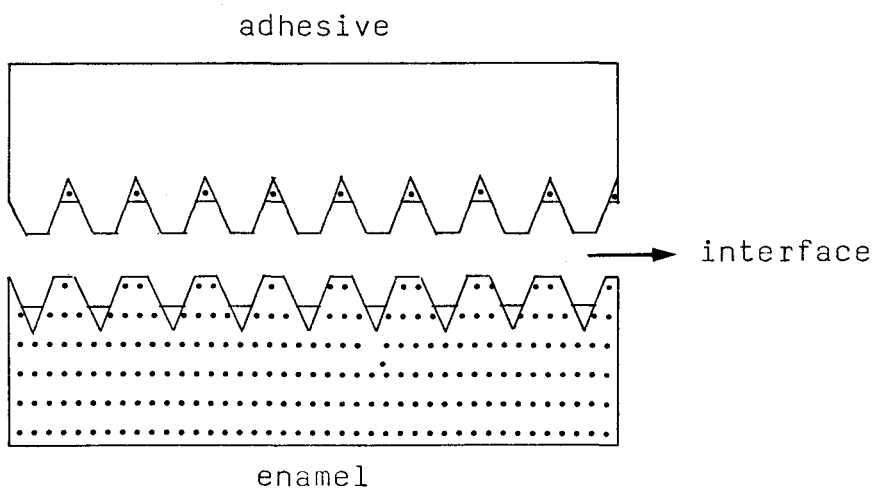


Illustration 3: Diagrammatic presentation of interfacial failure of a fractured bond on etched enamel.

## CHAPTER III.

### MATERIALS AND METHOD

#### TEETH:

In this investigation, 108 extracted bicuspid were randomly divided into six groups. Concise\*, Dyna Bond\*\*, and Endur\*\*\* were the three bonding systems tested. Each system was tested on 36 teeth and the testing time was divided into a one day period and 27 days period. A stainless steel mesh base bracket\*\*\*\* was bonded to each tooth.

The distribution of the upper and lower bicuspid between Concise, Dyna Bond, and Endur at two time intervals: 1 day and 27 days, is shown below.

	Concise	Dyna Bond	Endur	Total
U1	13	6	8	27
L1	5	12	10	27
U27	7	12	9	28
L27	11	6	9	26
Total	36	36	36	108

\* 3M - St. Paul, Minnesota

\*\* Unitek Orthodontic - Monrovia, California

\*\*\*Ormco - Glendora, California

\*\*\*\* Unitek Orthodontic - Monrovia, California



U1: Upper bicuspid tested 1 day after bonding  
L1: Lower bicuspid tested 1 day after bonding  
U27: Upper bicuspid tested 27 days after bonding  
L27: Lower bicuspid tested 27 days after bonding

In the group of Concise, one upper bicuspid fractured when the test started one day after bonding.

In the group of Endur, one upper bicuspid fractured when the test started 27 days after bonding.

Bicuspids extracted for orthodontic purpose were collected from Oral Surgeons of the Greater Chicago area. A container composed of distilled water mixed with 0.025 per cent of Thymol was supplied to each participating dental office. These containers were refrigerated. Immediately after each extraction, the tooth was rinsed in tap water for a few seconds before being placed into the container. Once the containers were collected from the different practices, the roots of the teeth were cleaned with a solid nail brush to eliminate any debris. Care was taken to avoid brushing the crown surface. These teeth were then replaced in a new container with distilled water mixed with 0.025 per cent Thymol. The age and sex of the patients were not considered in the samples collected.

#### BRACKETS:

Stainless steel edgewise siamese brackets with

contoured mesh base were attached to all teeth (Appendix A). The slot size was 0.022 inch by 0.028 inch. These brackets were standard type with no torque, angulation or rotation. In order to attach the appropriate type of bracket, the teeth were carefully screened to separate the upper and lower bicuspid.

#### ADHESIVES:

The three adhesive materials were all Bis GMA resin. Figures 1, 2, and 3, show the three types of bonding system. The manufacturers' instructions are shown on the Appendices B, C and D. For each brand the instructions were diligently followed.

#### SPECIMEN PREPARATION:

Grooves were prepared on the roots of the teeth with a bur to secure a better retention into the mold. These grooves were prepared to an average depth of 5/10 mm. Once the grooves were prepared, the teeth were placed back into the container. A wax mold was prepared into which dental stone\* was poured and allowed to harden (Fig. 4). Thirty minutes after the stone was poured, the specimen was transferred to a desiccator containing 100 per cent

\* Vel mix - Kerr Products



Figure 1. Concise adhesive kit.



Figure 2. Dyna Bond adhesive kit.



Figure 3. Endur adhesive kit.

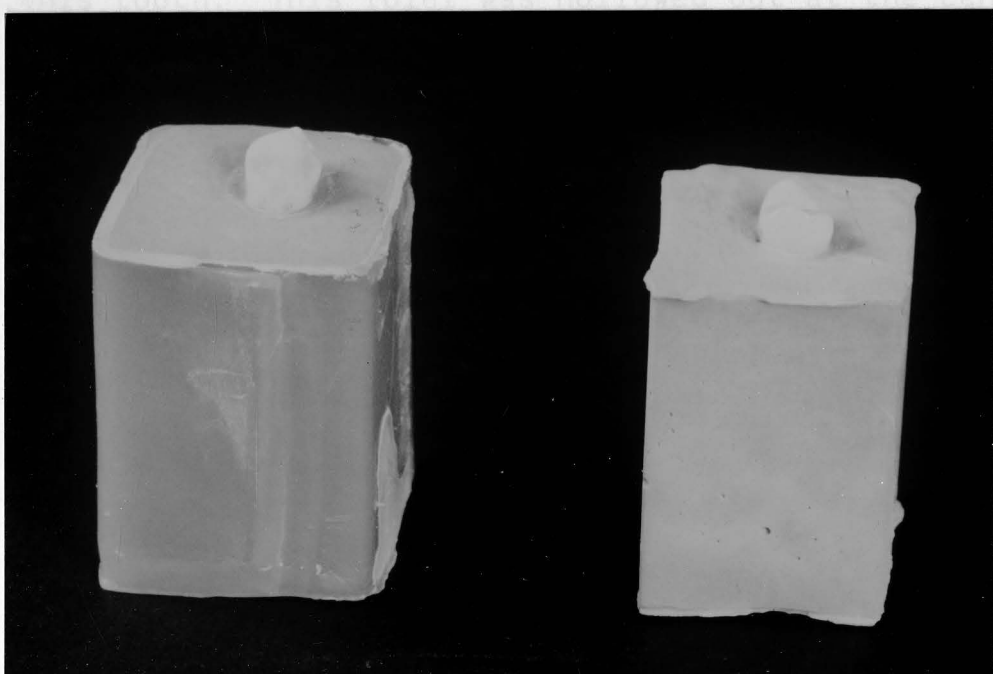


Figure 4. Preparation of tooth sample in wax mold.

distilled water (Fig. 5). This desiccator was maintained at a temperature of 37 degrees C. inside an oven\*.

One of the problems that had to be overcome in the experimental apparatus was the positioning of the tooth sample in such a way that it would ensure proper adjustment to the pulling motion of the upper jaw of the Instron Universal Testing Machine\*\*. The cutting of the mold in relation to the tooth was found to be a critical factor to the problem. As previously stated, the tooth was allowed to set in the mold in a reasonably upright position. A straight line, parallel to the buccal surface, was then marked on the mesial and distal slopes of the buccal cusp of the bicuspid. The next step was to superimpose a ruler on this tooth. This ruler was hollowed out at the center to allow the tooth to pass through (Fig. 6). The ruler was then adjusted to align with the pencil line marked on the occlusal surface of the tooth, with any one of the horizontal lines on the ruler (Fig. 7). The mesial and distal sides of the mold were then marked, based on two predetermined red dots on the ruler (Fig. 8 & 9). Not only the parallelism of the mesial and distal sides of the mold were ensured, but the buccal surface of the tooth was perpendicular to both sides of the mold (Fig. 10). Excess

\* Sargent low gradient analytical oven - E.H. Sargent,  
Chicago, Illinois

\*\* Instron Corporation - Canton, Massachusetts

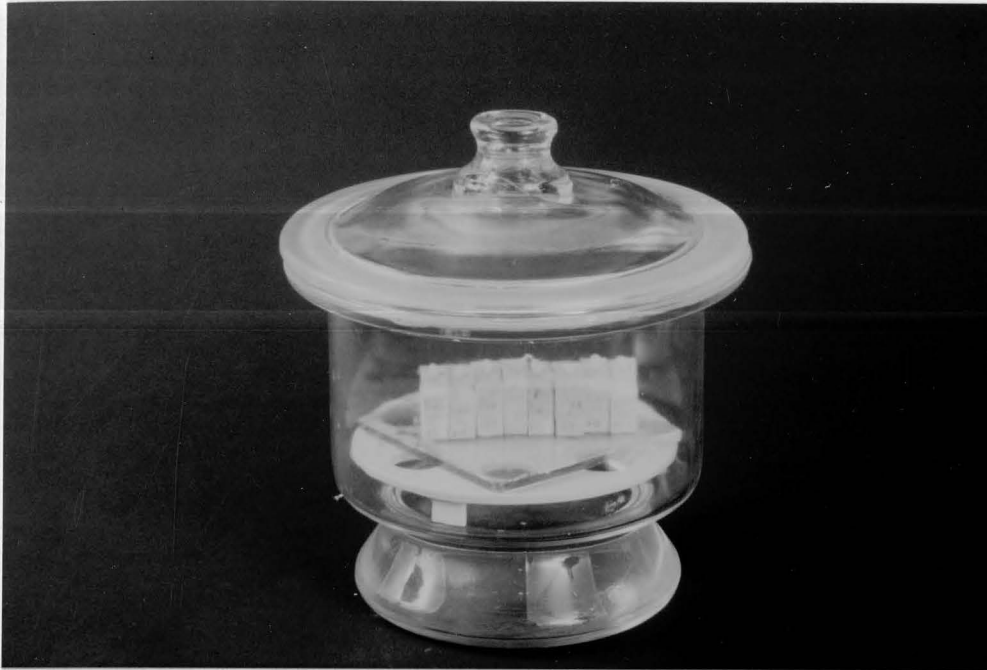


Figure 5. Dessicator.

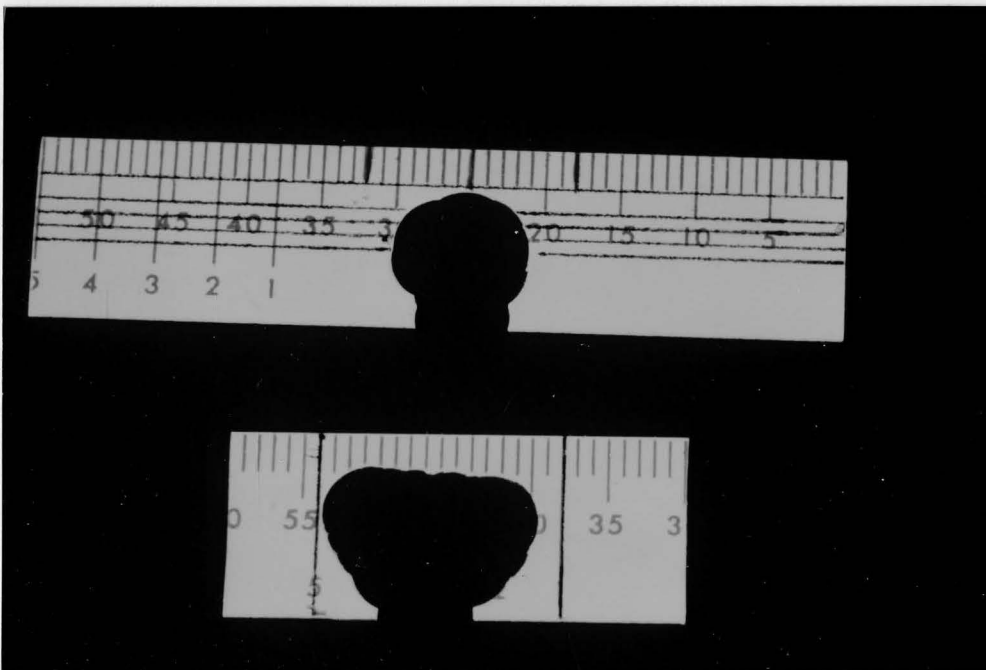


Figure 6. Rulers used for preparing stone mold.

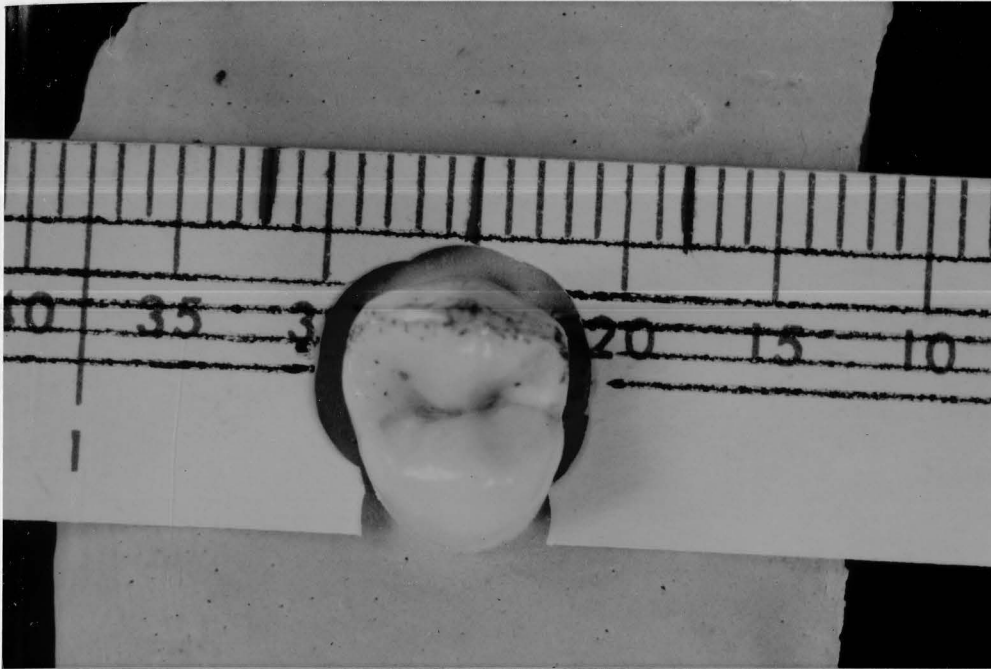


Figure 7. Alignments of the ruler and occlusal surface of the tooth.

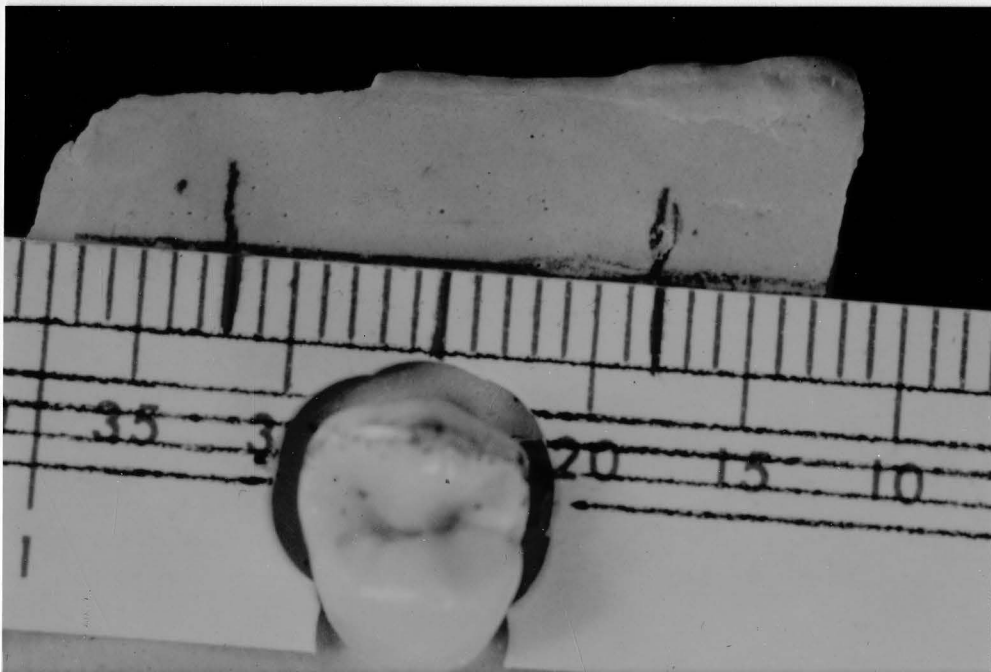


Figure 8. Buccal marks drawn on the stone mold.

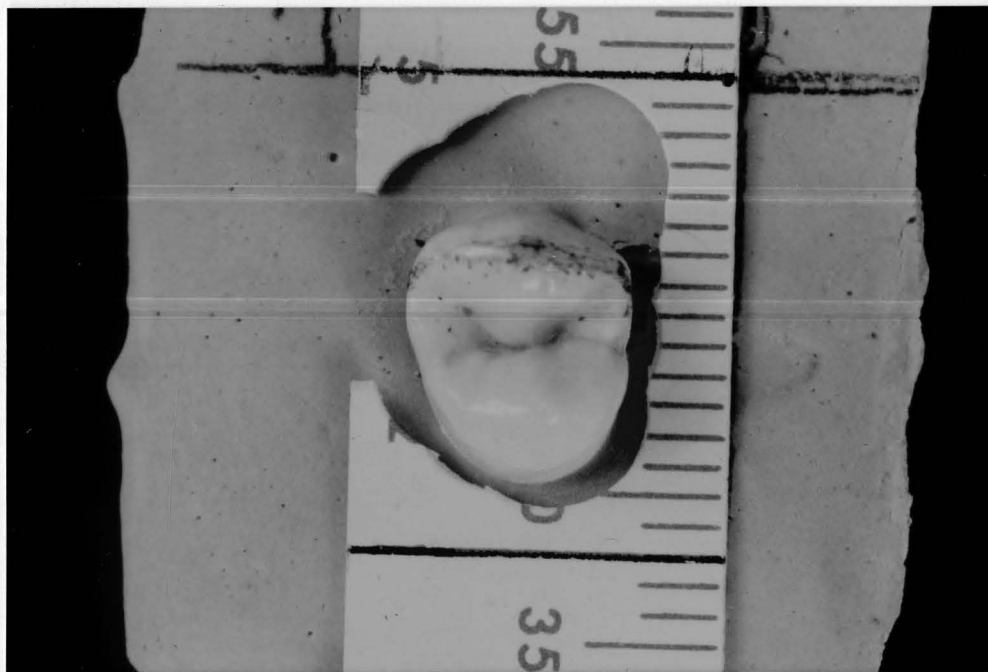


Figure 9. Perpendicular line drawn to the buccal line making the proximal sides parallel to each other.



Figure 10. Lines drawn of a prepared stone mold.



dental stone was then trimmed away on the proximal sides of the mold. The total width of the mold was no larger than the width of the Instron's lower jaw (Fig. 11 & 12).

Each sample was identified by the date and time of bonding with the first letter of the bonding system on the frontal part of the mold (Fig. 18). All the manufacturers' instructions were followed accordingly. However, there were several similar steps: 1) the enamel surface was pumiced for 30 seconds with a non-fluoridated prophylactic powder; 2) the enamel surface was rinsed with tap water and then dried with oil free compressed air for 60 seconds; 3) the enamel surface was etched with the respective manufacturer's phosphoric acid liquid; 4) after etching, the specimens were rinsed with a liberal spray of tap water for 30 seconds and dried with oil free compressed air for 60 seconds. The etching was judged acceptable when a chalky appearance seemed uniform on the buccal surface of the tooth. In two instances, it was necessary to re-etch for 30 seconds; 5) the sealants were mixed and applied thinly on the etched surface. For Concise and Dyna Bond, the same mix was used for six samples, while the Endur sealant took one tooth per mix; 6) the adhesive was applied immediately to the bracket and adapted on the tooth surface after the sealant was painted. No more than one mix at a time was used; 7) the bracket was applied to the tooth with a constant gentle pressure for 30 seconds. The use of a tweezer facilitated

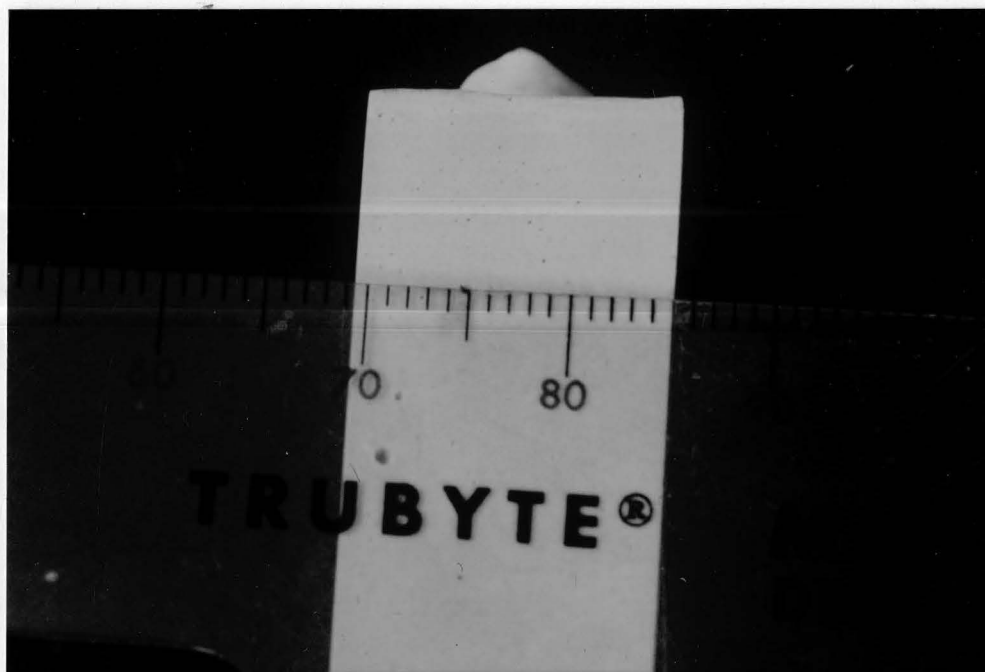


Figure 11. Parallelism of the proximal sides  
(frontal view).

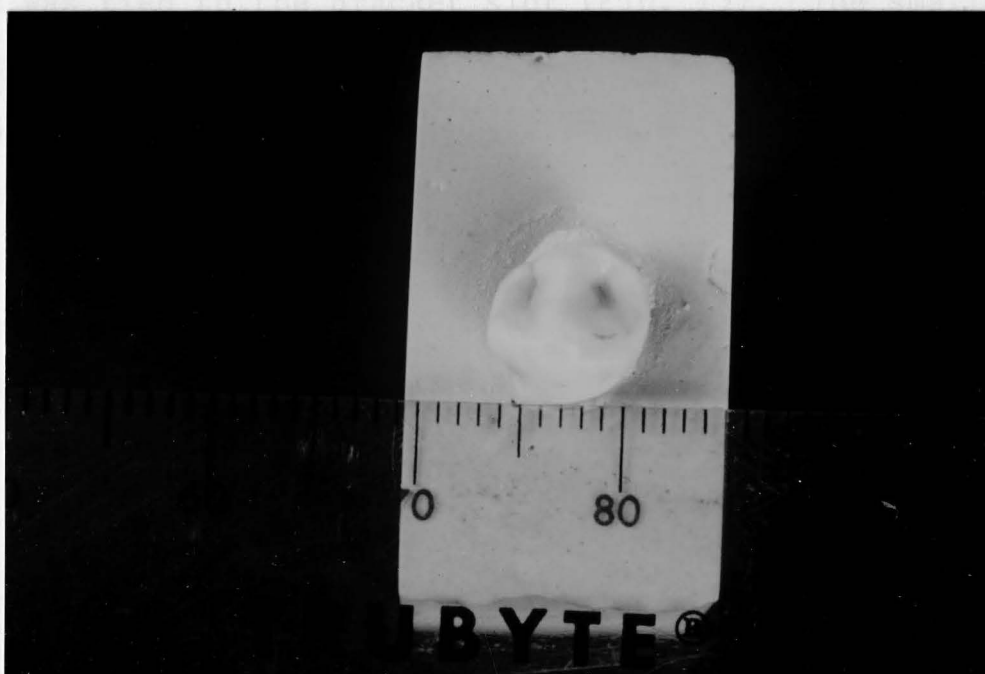


Figure 12. Parallelism of the proximal sides  
(seen from above).

the handling and application of the bracket; 8) no attempt was made to individually contour the base of the bracket to the tooth surface. This was considered to be a difficult procedure and the accuracy of the adaptation could not be properly judged; 9) no attempt was made to remove excess adhesive from the periphery of the bracket in order to prevent unnecessary movement during setting time. The samples were allowed to set for 30 minutes before returning to the desiccator. 10) During the bonding procedure, the inferior portion of the bracket was made perpendicular to the proximal sides of the mold to ensure an easy adjustment of the bracket to the vertical pull of the Instron Machine. In this step, a "L" shape 0.021 x 0.025 inch stainless steel wire was tied to the bracket slot (Fig. 13). The smaller portion of the "L" wire was then made to come in contact with a mixing glass slab, which in turn was closely approximated to the proximal side of the mold (Fig. 14). This means the slot and the inferior part of the bracket wings were perpendicular to the proximal sides. 11) The middle of the bracket was also centered along the mid portion of the tooth buccal surface.

#### PROCEDURE:

Each sample was tested for shear strength by the tension mode of the Instron Machine. The samples were tested during two periods of one day (plus or minus four

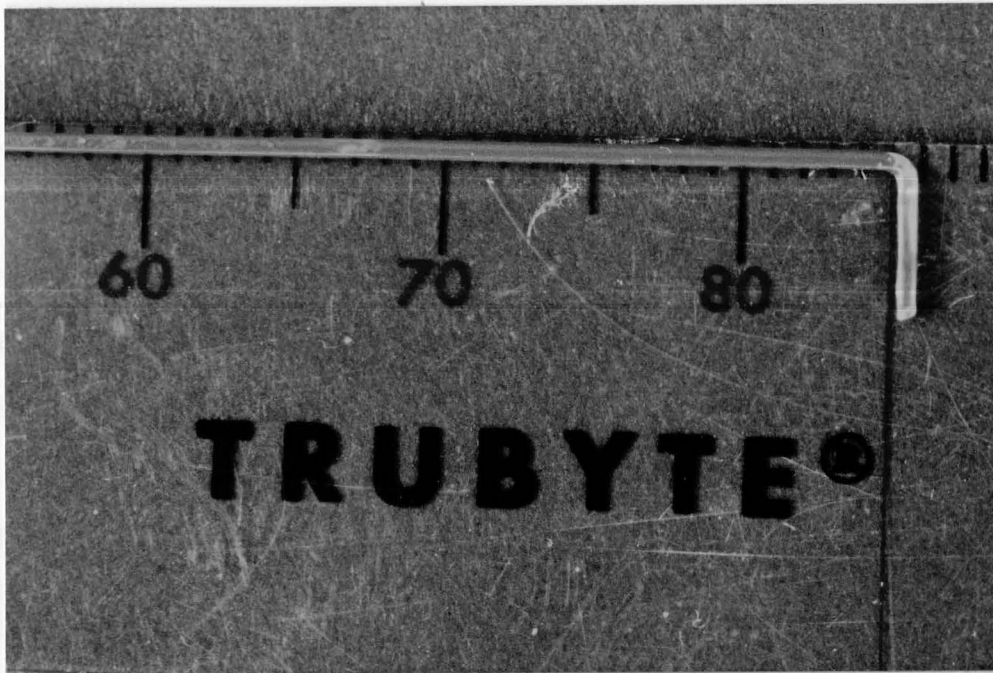


Figure 13. "L" shape "guiding" stainless steel wire

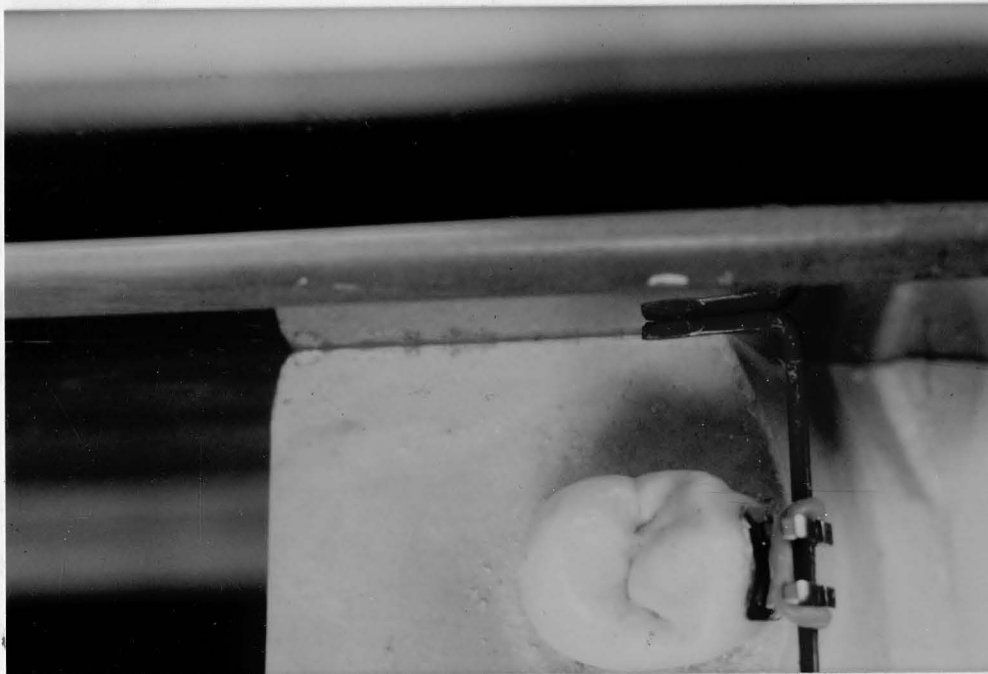


Figure 14. Procedure for securing the inferior part of the bracket perpendicular to the proximal sides.

hours), and 27 days (plus or minus 12 hours). The samples were randomly selected for testing, regardless of whether those were upper or lower bicuspid.

A special harness was fabricated for the shear action. This harness consisted of a "U" shaped three millimeters thick stainless steel\* (Fig. 15). The upper ends of the "U" shaped harness were attached to the superior jaw of the Instron Machine. The horizontal part of this harness was bevelled to facilitate its fitting underneath the inferior portion of the bracket (Fig. 16).

A portion of the mold was removed on the frontal side to allow the fitting of the harness underneath the bracket (Fig. 17). A "L" shape 0.021 X 0.025 inch wire was tied to the slot, with the longer portion in the vertical position (Fig. 18). Then the harness was adjusted in such a way to align its vertical ends parallel to the longer portion of the wire. Thus the horizontal bar was parallel to the inferior wings of the bracket (Fig. 19, 20). This prevented rotational movements during testing.

Parallelism of the bracket-adhesive-enamel interface to the harness was also necessary. For this, the mold was adjusted to the harness. The longer portion of the wire being always in the vertical position the mold was then

\* Jordan Precision Instruments - Bollingbrook, Illinois

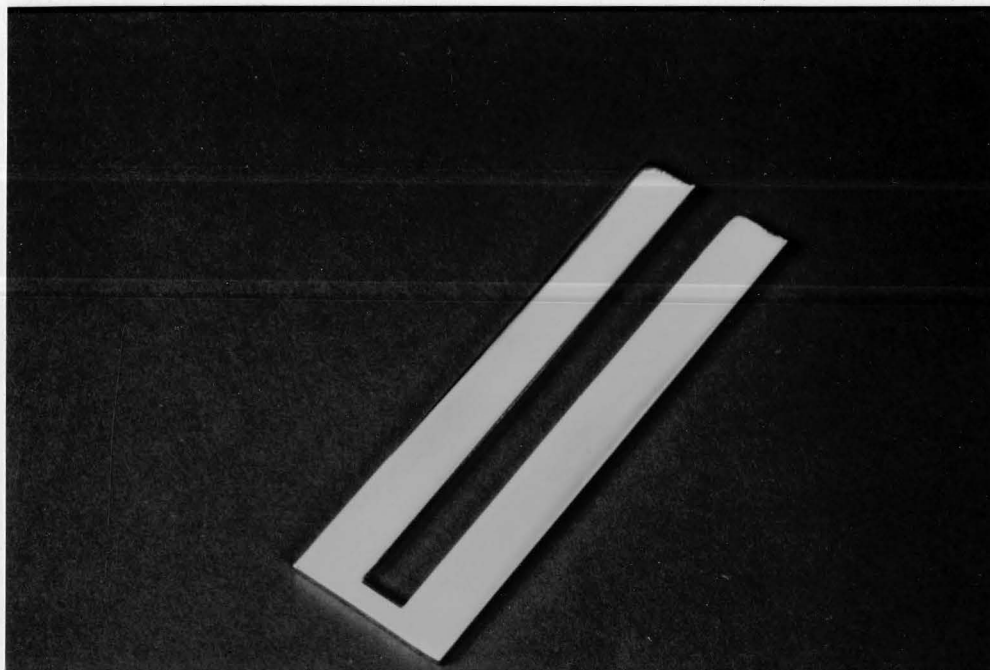


Figure 15. Harness.



Figure 16. Close-up of the bevelled part of the harness.

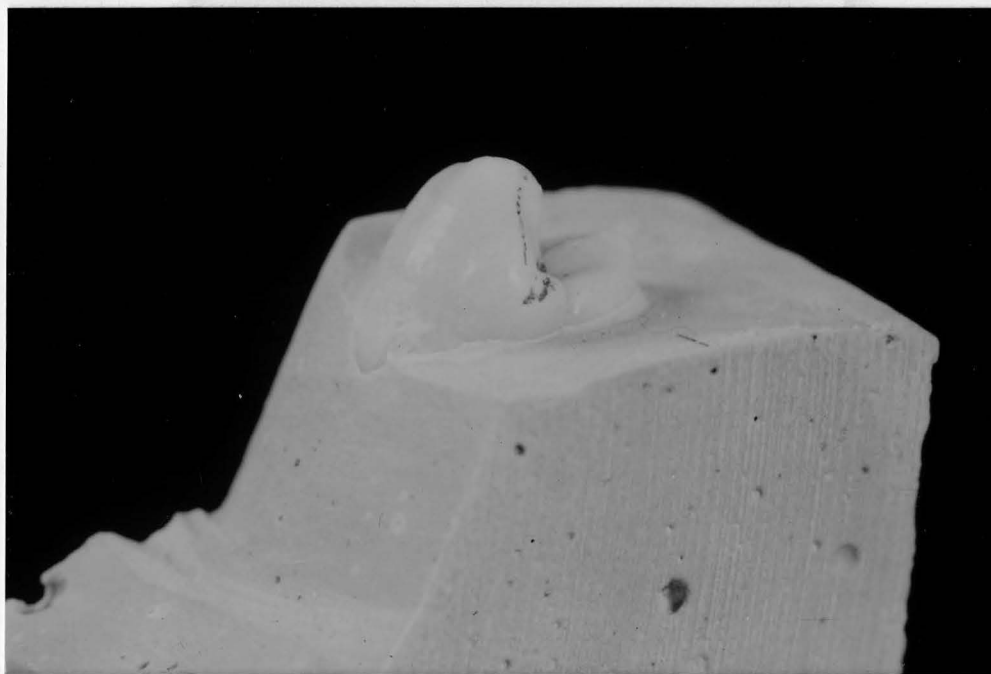


Figure 17. Profile view of the mold.

Figure 18. Frontal view of the right breast sample.

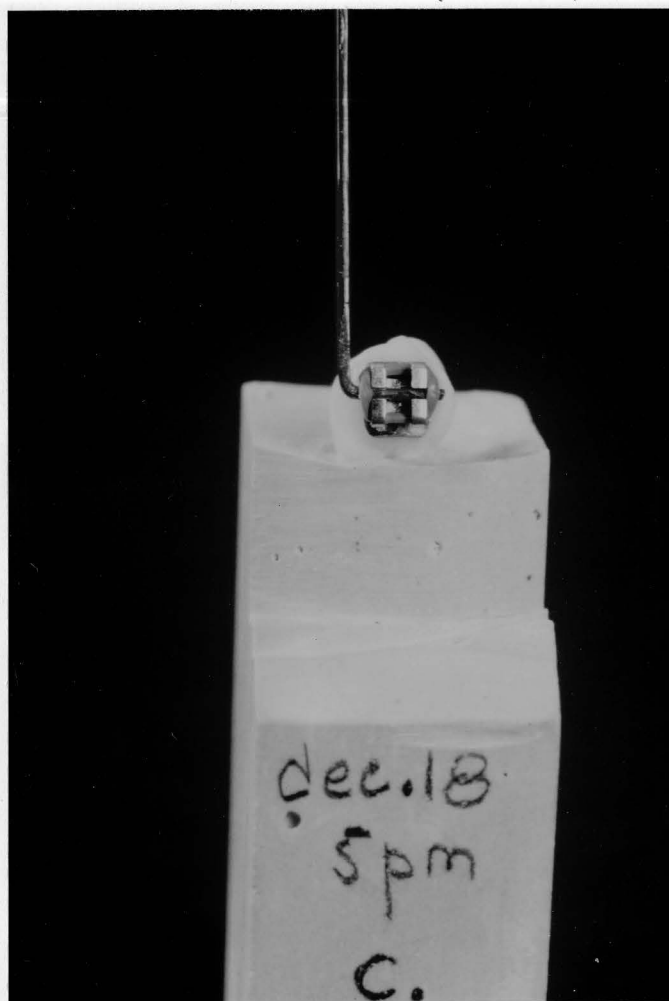


Figure 18. Frontal view of the tooth bracket sample.



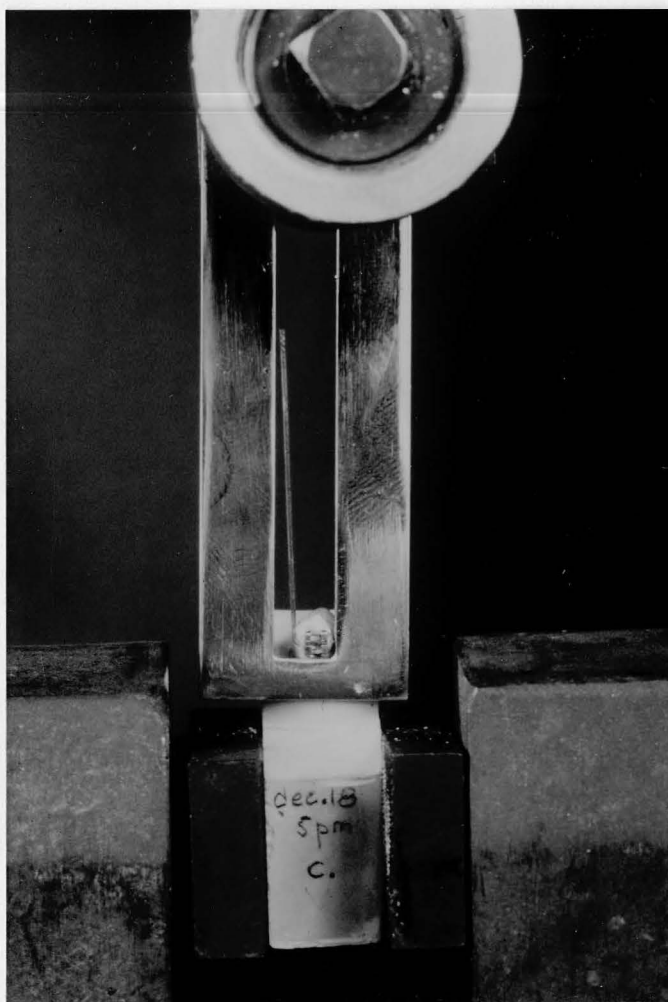


Figure 19. Frontal view of the attached mold and "guiding" wire before adjustment.

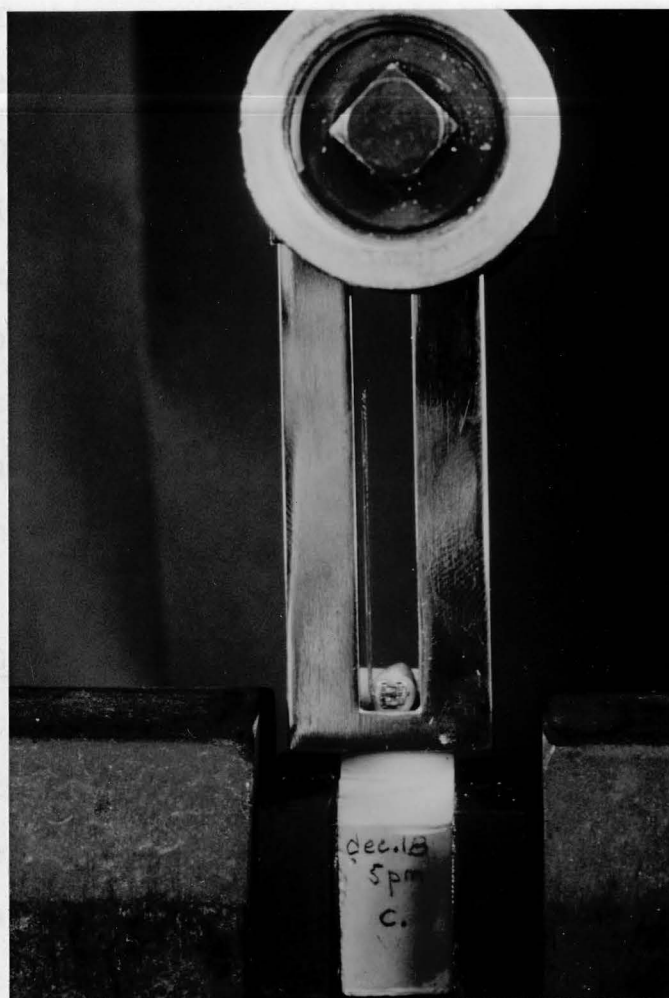


Figure 20. Frontal view of the attached mold and "guiding" wire after adjustment.

rotated, if necessary, to achieve parallelism of the wire and the harness (Fig. 21, 22 & 23). This final adjustment permitted the shear action on the bracket.

The Instron was loaded with a 100 pounds cell. The crosshead speed was adjusted to 0.05 inch per minute, and the recording graph was operated at a chart speed of 20 inches per minute. The shear mode was applied until a failure occurred. The point of each adhesive failure was recorded in pounds on the recording graph.

The time lapse between the removal of the specimen from the decanter and the start of testing was no longer than 11.5 minutes.

#### MICROSCOPIC OBSERVATION:

All the samples were stored after shearing test at room temperature and room humidity. The samples were viewed under a stereoscopic microscope\* with 40X magnification. No special preparation of the samples was employed to ensure easier visualization. A tungsten light was proved fairly sufficient to determine the different types of failures encountered after testing.

All the samples were viewed three times under the microscope at three different periods in order to find

\* Olympus stereoscopic microscope, Model X-Tr

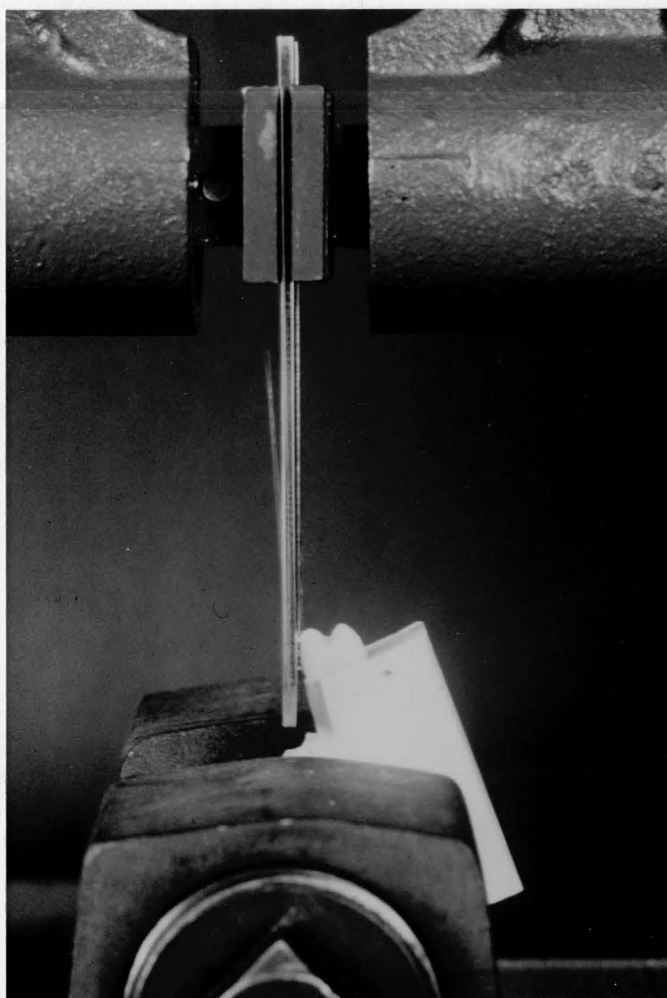


Figure 21. Lateral view of the attached mold and "guiding" wire before adjustment.

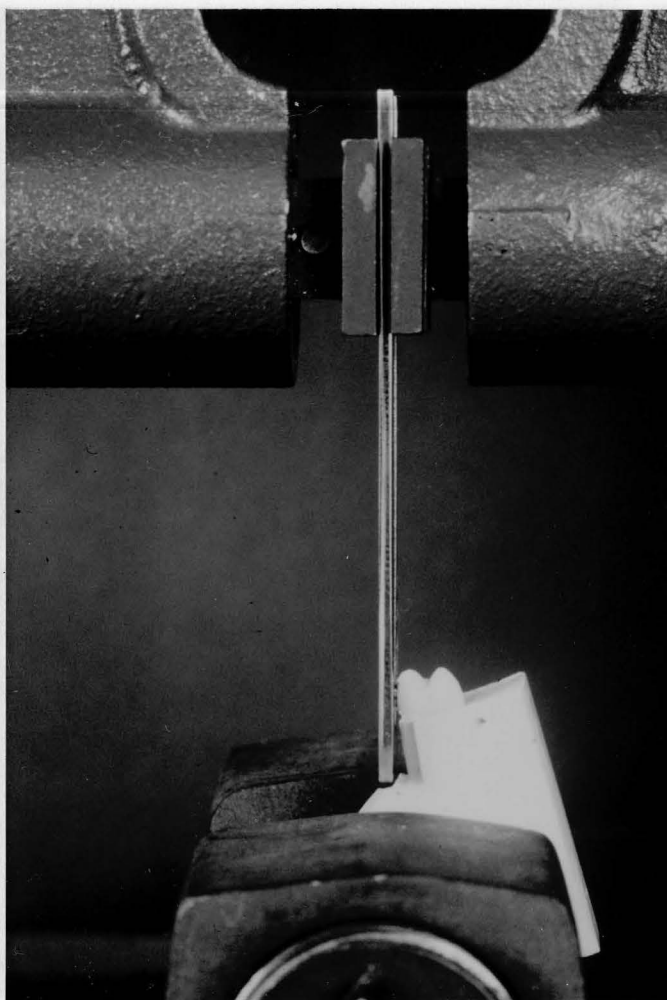


Figure 22. Lateral view of the attached mold and "guiding" wire after adjustment.



Figure 23. Another view of the adjusted testing sample.

more consistant results. After the third time, the results were concordant and the samples were then classified in three different groups according to the findings under microscopic observations.

A sample of each brand showing each of the failures was choosen randomly. Then a picture was taken at 4X magnification, with a camera\* mounted on the microscope.

#### STATISTICAL DESIGN:

Details of the statistical design may be found in Bruning and Kintz (1977). The statistical design employed a Completely Randomized Design. If the analysis of variance was statistically significant, a Duncan's Multiple Range Test for comparisons among the means was also performed to determine significant differences among main effect factors. A Chi-Square was used to test the hypothesis of possible relationships between the variables. When the Chi-Square Test showed that there were statistically significant relationships between the variables, the Contingency Coefficient (C) was determined to give an indication of the extent of the relationships.

\* Camera OM2 - Olympus

## CHAPTER IV.

### RESULTS

The results of this investigation were presented in two parts: 1) Experimental Results and 2) Microscopic Observations.

#### EXPERIMENTAL RESULTS:

The individual data for the shear strength mode are shown in Appendices E, F, G, H, I, and J. A statistical summary of these data including the mean, the standard deviation and absolute range of the shear strength was shown in Table I.

Most of the testings were uneventful and testing completed except for two samples. These two samples could not be tested due to bond failure or tooth fracture while the jig was being attached.

The results were pooled and a Completely Randomized Design was performed. Table II showed the results of the analysis of variance. This test indicated a significant difference among the means of adhesive materials ( $p < 0.001$ ). Duncan's test for comparison among these means was performed



TABLE I

Statistical summary of the shear strength of the three direct bonding materials measured at the first and the 27th day (expressed in pounds).

SAMPLE	MEAN	STANDARD DEVIATION	ABSOLUTE RANGE
Concise 1st day 27th day	12.98 15.28	2.93 3.01	9.30-17.50 11.02-24.40
Dyna Bond 1st day 27th day	10.96 16.39	4.45 3.63	4.48-18 9.70-22.5
Endur 1st day 27th day	10.82 10.87	1.94 2.26	8.82-14.40 8.81-13.90

TABLE II

Analysis of variance between the three groups of composites tested at the first day and the 27th day.

SOURCE	SS	df	ms	F	p
Total	1523.83	105	--	--	--
Between Groups	537.87	5	105.57	10.91	$p < .001$
Within Groups	985.96	100	9.86	--	--

to determine the groups that were significantly different from the others. The results were shown in Table III at five per cent and one per cent level of significance.

No statistical difference between the mean shear strength of Concise, Dyna Bond and Endur could be demonstrated one day after bonding ( $p > 0.05$ ). There was also no statistical difference between the mean shear strength of Endur tested after 27 days compared to the mean shear strength of Concise or Dyna Bond tested after one day ( $p > 0.05$ ). The same was true for the mean shear strength of Concise tested after 27 days compared to the mean shear strength of Dyna Bond after 27 days ( $p > 0.05$ ).

However, the mean shear bond strength of Endur tested after 27 days was weaker than that of Concise and Dyna Bond tested after 27 days ( $p < 0.01$ ). Concise showed a statistically stronger mean shear strength when tested after 27 days than after one day ( $p < 0.05$ ). Dyna Bond also showed a statistically stronger mean shear strength when tested after 27 days than after one day ( $p < 0.01$ ). After 27 days, 1) the mean shear strength of Concise was statistically stronger than the mean shear of Dyna Bond tested at one day ( $p < 0.01$ ); 2) the mean shear strength of Dyna Bond was statistically stronger than the mean of Concise tested at one day; 3) the mean shear strength of Concise was comparable to the mean shear strength of Dyna Bond; 4) the mean shear strength of Endur was weaker.

TABLE III

Duncan's multiple range test for multiple comparisons of the mean of the six groups tested at the first and the 27th day.

	DIFFERENCE OF THE MEANS	RANGE	C	p
E 1 vs E 27	10.87 - 10.82 = .05	2	2.10	p > 0.05
E 1 vs D 1	10.96 - 10.82 = .14	3	2.21	p > 0.05
E 1 vs C 1	12.98 - 10.82 = 2.16	4	2.29	p > 0.05
E 1 vs C 27	15.28 - 10.82 = 4.46	5	3.04	p < 0.01
E 1 vs D 27	16.39 - 10.82 = 5.57	6	3.08	p < 0.01
E 27 vs D 1	10.96 - 10.87 = .09	2	2.10	p > 0.05
E 27 vs C 1	12.98 - 10.87 = 2.11	3	2.21	p > 0.05
E 27 vs C 27	15.28 - 10.87 = 4.41	4	2.95	p < 0.01
E 27 vs D 27	16.39 - 10.87 = 5.52	5	3.04	p < 0.01
D 1 vs C 1	12.98 - 10.96 = 2.02	2	2.10	p > 0.05
D 1 vs C 27	15.28 - 10.96 = 4.32	3	2.90	p < 0.01
D 1 vs D 27	16.39 - 10.96 = 5.43	4	2.95	p < 0.01
C 1 vs C 27	15.28 - 12.98 = 2.3	2	2.10	0.05 > p > 0.01
C 1 vs D 27	16.39 - 12.98 = 3.41	3	2.90	p < 0.01
C 27 vs D 27	16.39 - 15.28 = 1.11	2	2.10	p > 0.05

C = Minimum critical differences for the given range of comparisons.

p = Level of significance

C 1 = Concise after 1 day

D 1 = Dyna Bond after 1 day

E 1 = Endur after 1 day

C 27 = Concise after 27 days

D 27 = Dyna Bond after 27 days

E 27 = Endur after 27 days

The data of the upper bicuspid versus the lower bicuspid tested at one day and 27 days, were pooled and Appendices I, K, and L showed the results. Using a Completely Randomized Design, the analysis of variance revealed a statistical significant difference ( $p < 0.05$ ) among the mean shear strength of the upper and lower bicuspid (Table IV). Consequently, a Duncan's test was performed and Table V showed the results.

The results at the first day showed no statistical difference between the upper and lower bicuspid. This was also true for the results at the 27th day. The mean of the lower bicuspid showed no difference between the first and the 27th day.

However, the mean shear strength of the lower bicuspid after 27 days was statistically greater than the mean of the upper bicuspid tested after one day, and the mean shear strength of the lower bicuspid after one day was statistically greater than the mean shear strength of the upper bicuspid tested after 27 days. The mean shear strength of the upper bicuspid tested after 27 days was greater than the mean of the upper bicuspid after one day.

The results were interesting but too vague because they did not distinguish the different type of materials used. The same tests were performed, by comparing the upper versus the lower bicuspid at the first day and twenty-seventh day for each of the composites. The results were

TABLE IV

Analysis of variance between the mean shear strength of upper and lower bicuspidis recorded at the first and 27th day.

SOURCE	SS	df	ms	F	p
Total	1781.42	105	--	--	--
Between	172.03	3	57.34	3.63	$p < 0.05$
Within	1609.39	102	15.78	--	--

TABLE V

Duncan's test of the mean shear strength of upper bicuspid versus the mean of lower bicuspid recorded at the first and 27th day.

	DIFFERENCE OF THE MEANS	RANGE	C	p
U 1 vs L 1	11.61 - 11.48 = 0.13	2	2.156	$p > 0.05$
U 1 vs L 27	13.76 - 11.48 = 2.28	3	2.272	$0.05 > p > 0.01$
U 1 vs U 27	14.34 - 11.48 = 2.86	4	2.349	$0.05 > p > 0.01$
L 1 vs L 27	13.76 - 11.61 = 2.150	2	2.156	$p > 0.05$
L 1 vs U 27	14.34 - 11.61 = 2.72	3	2.272	$0.05 > p > 0.01$
L 27 vs U 27	14.34 - 13.76 = 0.58	2	2.156	$p > 0.05$

U 1 = Upper premolar at the 1st day  
 U 27 = Upper premolar at the 27th day  
 L 1 = Lower premolar at the 1st day  
 L 27 = Lower premolar at the 27th day

shown in Appendices M, N, and O. A Completely Randomized Design was used for each of the brand and the analysis of variance was shown in Tables VI, VII, and VIII.

For Concise and Endur, no statistically significant difference existed between the upper and lower bicuspid, at either the first or 27th day.

However, with Dyna Bond, a statistically significant difference between the upper and lower bicuspid at the two testing periods did exist. Thus a Duncan's test was performed and the results appeared in Table IX.

No statistically significant difference was demonstrated between: 1) the mean shear strength of the upper and lower bicuspid after one day; 2) the mean of the lower bicuspid after one day or 27 days; and 3) the mean of the upper and lower bicuspid at 27th day. However, the mean of the lower bicuspid tested after 27 days was greater than the mean of the upper bicuspid after one day. The mean shear of the upper bicuspid was greater at 27 days than at one day. The mean of the lower bicuspid tested at one day was greater than the mean of the upper ones tested after 27 days.

It was important from a clinical standpoint to know the frequency of the three different types of failure for each of the three composites, without taking into consideration the two testing periods. A complex chi-square was used and the results were shown in Table X. Endur



TABLE VI

Endur analysis of variance between the mean shear strength of upper versus lower bicuspid tested at the first and 27th day.

SOURCE	SS	df	ms	F	p
Total	146.23	34	--	--	--
Between gp	10.06	3	3.35	0.76	$p > 0.05$
Within gp	136.17	31	4.39	--	--

TABLE VII

Concise analysis of variance between the mean shear strength of upper versus the lower bicuspid tested at the first and 27th day.

SOURCE	SS	df	ms	F	p
Total	606.19	34	--	--	--
Between gp	28.38	3	9.46	0.507	$p > 0.05$
Within gp	577.81	31	18.64	--	--

TABLE VIII

Dyna Bond analysis of variance between the mean shear of upper versus the lower bicuspid tested at the first and 27th day.

SOURCE	SS	df	ms	F	p
Total	826.32	35	--	--	--
Between gp	303.71	3	101.24	6.20	$p < 0.01$
Within gp	522.61	32	16.33	--	--

TABLE IX

Duncan's test of Dyna Bond for the mean shear strength of the upper versus the lower bicuspid tested at the first and 27th days.

	DIFFERENCE OF THE MEANS	RANGE	C	p
U 1 vs L 1	11.91 - 9.05 = 2.86	2	4.13	p > 0.05
U 1 vs L 27	15.63 - 9.05 = 6.58	3	5.81	p < 0.01
U 1 vs U 27	16.77 - 9.05 = 7.72	4	5.94	p < 0.01
L 1 vs L 27	15.63 - 11.91 = 3.72	2	4.13	p > 0.05
L 1 vs U 27	16.77 - 11.91 = 4.86	3	4.35	0.05 > p > 0.01
L 27 vs U 27	16.77 - 15.63 = 1.14	2	4.13	p > 0.05

U 1 = Upper bicuspid at 1st day  
 U 27 = Upper bicuspid at 27th day  
 L 1 = Lower bicuspid at 1st day  
 L 27 = Lower bicuspid at 27th day

TABLE X

Relationships between the types of composite and the types of failure recorded at the first and 27th day.

BRAND	FAILURE			TOTAL
	ENAMEL	BRACKET	COMBINATION	
Concise	17 48.57%	12 34.29%	6 17.14%	35
Dyna Bond	5 13.89%	25 69.44%	6 16.67%	36
Endur	2 5.71%	29 82.86%	4 11.43%	35
Total	24	66	16	106

$$\chi^2 = 23.588 \quad (p < 0.001)$$

$$\chi^2 = \text{Chi square}$$

$$C = \sqrt{0.182} = 0.426$$

$$C = \text{Coefficient of contingency}$$

showed the highest percentage of bracket adhesive failure (82.86%), and the lowest percentage of enamel adhesive failure (5.71%). Concise showed the highest percentage of enamel adhesive failure (48.57%) and the lowest percentage of bracket adhesive failure (34.29%).

Data on Appendices P, Q, R, S, T, and U showed correlation, if any, between the type of failure and the amount of force exerted. A complex chi-square (Table XI) was performed. No correlation could be demonstrated.

#### MICROSCOPIC OBSERVATION:

The stereoscopic microscope revealed various types of failures that were classified into three groups: a) adhesive failure occurring on the enamel tooth surface (Ill. 4a); b) adhesive failure occurring on the mesh-base of the bracket (Ill. 4b); c) and the failure occurring both on the enamel and on the mesh-base bracket (Ill. 4c).

This classification was made by visual observation of the amount of composite remaining on either the enamel or the mesh-base surface. When the amount of remaining composite on the enamel was estimated to be more than 50 per cent of the total surface of the interface, the failure was classified as a metal-mesh adhesive failure (Fig. 24, 25, 26). On the contrary, when the amount of remaining bonding agent on the enamel was estimated to be less than 50 per cent of the total area, the failure was classified as an

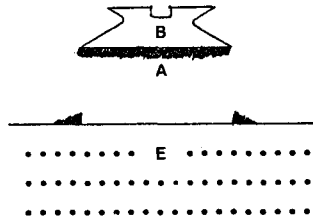
TABLE XI

Relationships of the mean shear strength between the force developed at failure, and the type of failure (expressed in pounds).

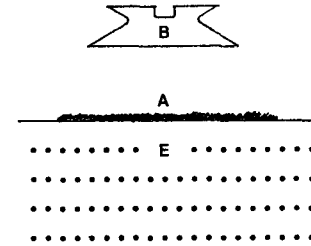
BRAND	FAILURE			TOTAL
	ENAMEL	BRACKET	COMBINATION	
C 1	10.30	12.86	14.14	37.3
C 27	15.51	14.78	15.80	46.09
D 1	8.39	12.69	10.27	31.35
D 27	17.9	16.52	12.9	47.32
E 1	13.76	10.75	8.96	33.47
E 27	5.60	11.36	10.52	27.48
Total	71.46	78.96	72.59	223.01

$$\chi^2 = 5.23 \text{ (} p > 0.05 \text{)}$$

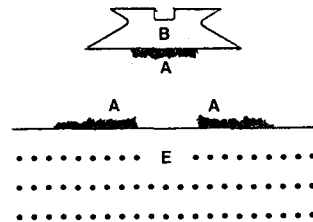
C 1 = Concise tested at the 1st day  
 C 27 = Concise tested at the 27th day  
 D 1 = Dyna Bond tested at the 1st day  
 D 27 = Dyna Bond tested at the 27th day  
 E 1 = Endur tested at the 1st day  
 E 27 = Endur tested at the 27th day



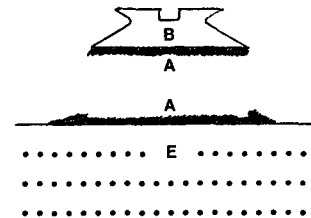
a) enamel adhesive failure



b) bracket adhesive failure



c) combination adhesive failure



d) cohesive failure

Illustration 4: Diagrammatic presentation of adhesive and cohesive failures.  
(A = adhesive, B = bracket, E = enamel)



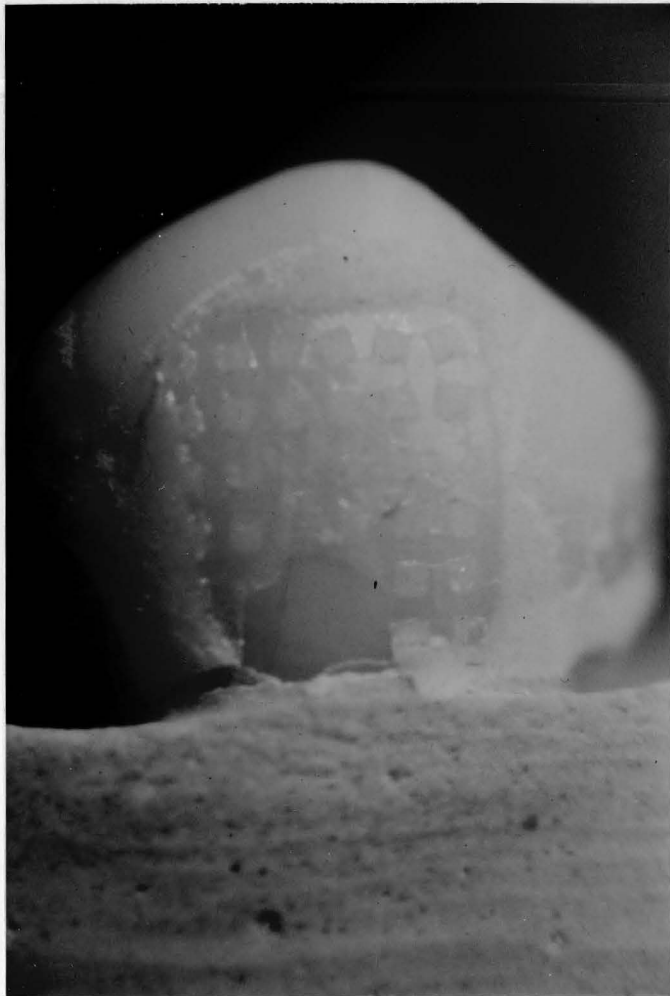


Figure 24. Concise bracket adhesive failure (4X magnification).

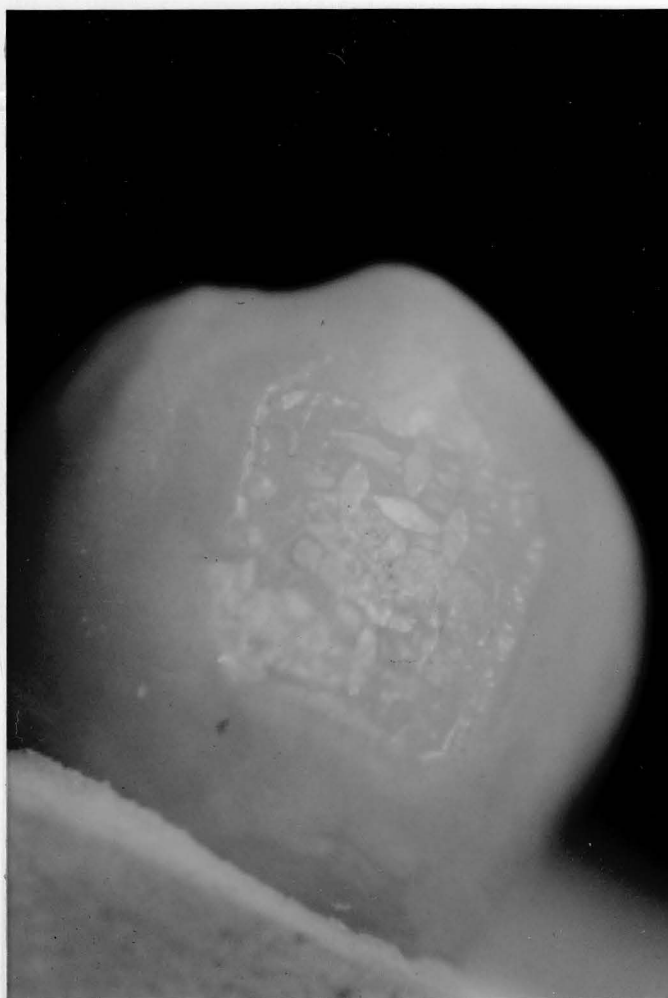


Figure 25. Dyna Bond bracket adhesive failure (4X magnification).

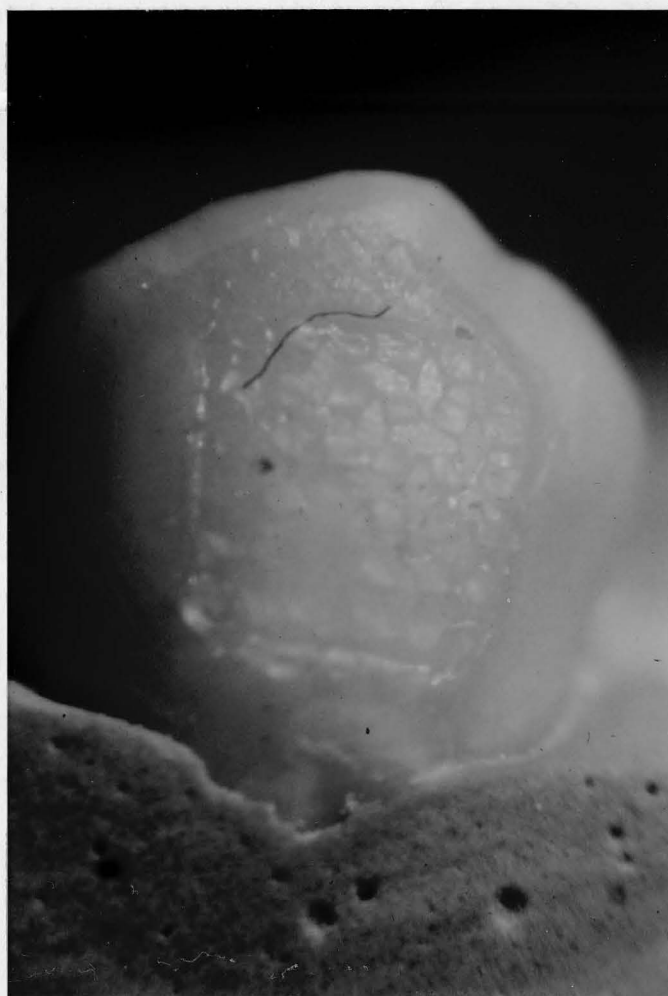


Figure 26. Endur bracket adhesive failure (4X magnification).

adhesive enamel failure (Fig. 27, 28, 29). The third type occurred when the remaining composite on the enamel surface was 50 per cent of the total interface, the other remaining 50 per cent being on the mesh base (Fig. 30, 31, 32).

For the purpose of discussion, the simplification of these three types have been called: a) enamel, b) bracket, and c) combination failure.

It was very difficult, and sometimes impossible, to visualize any differences between these three composites. The composite appeared under magnification to be homogeneous smooth, and brilliant. The bracket failure seemed to be more distinct in the Concise and Dyna Bond than with Endur (Fig. 24, 25, 26). For the enamel adhesive failure, it was impossible to distinguish any difference on the tooth enamel surface between the three composites.

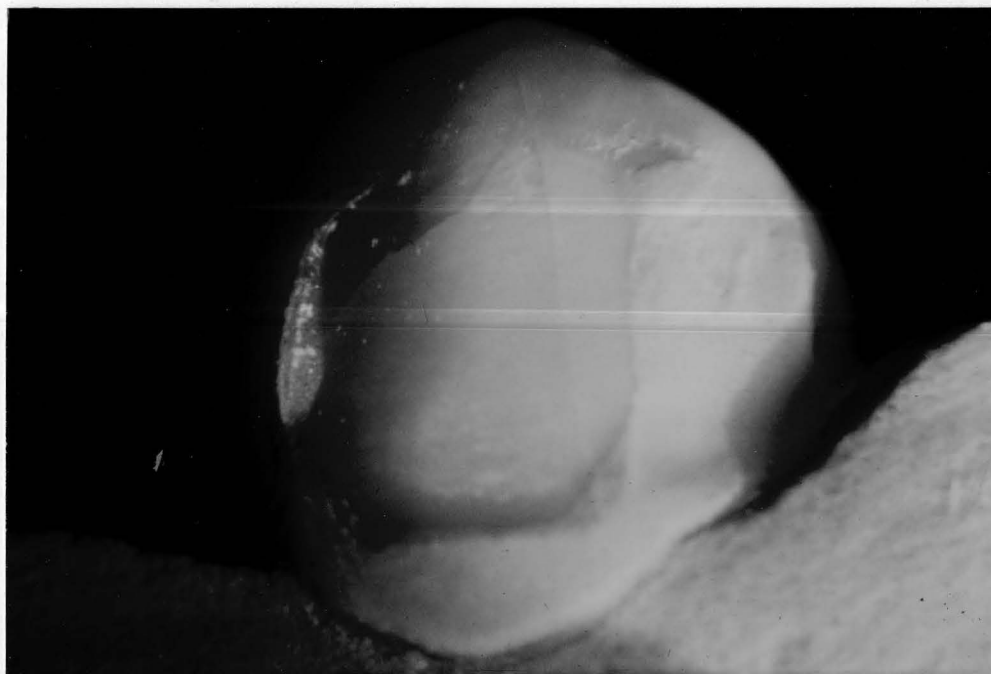


Figure 27. Concise enamel adhesive failure (4X magnification).

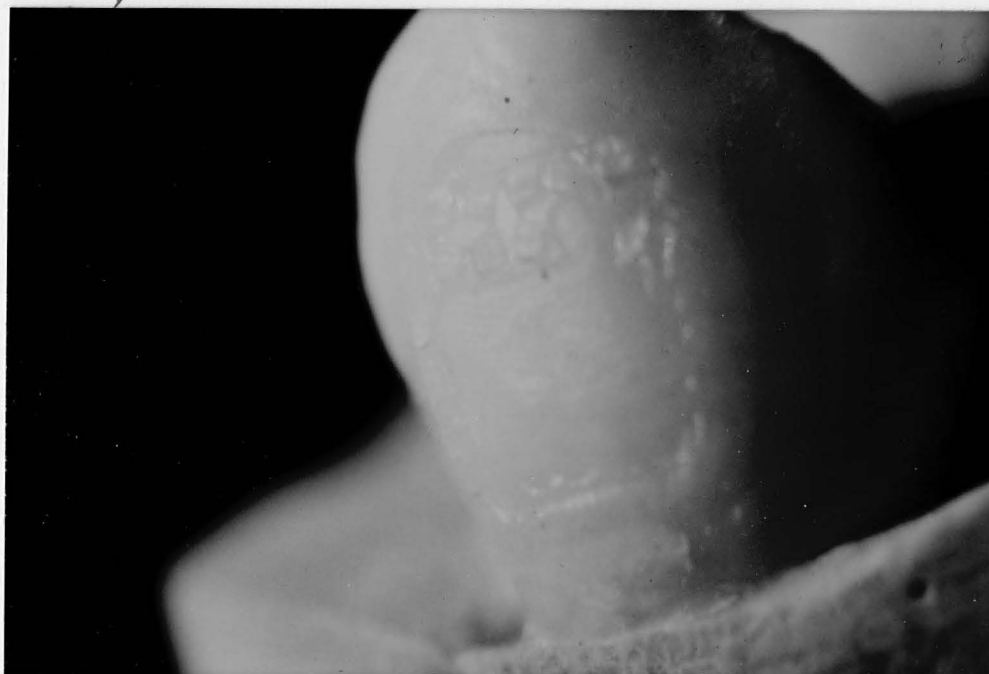


Figure 28. Dyna Bond enamel adhesive failure (4X magnification).

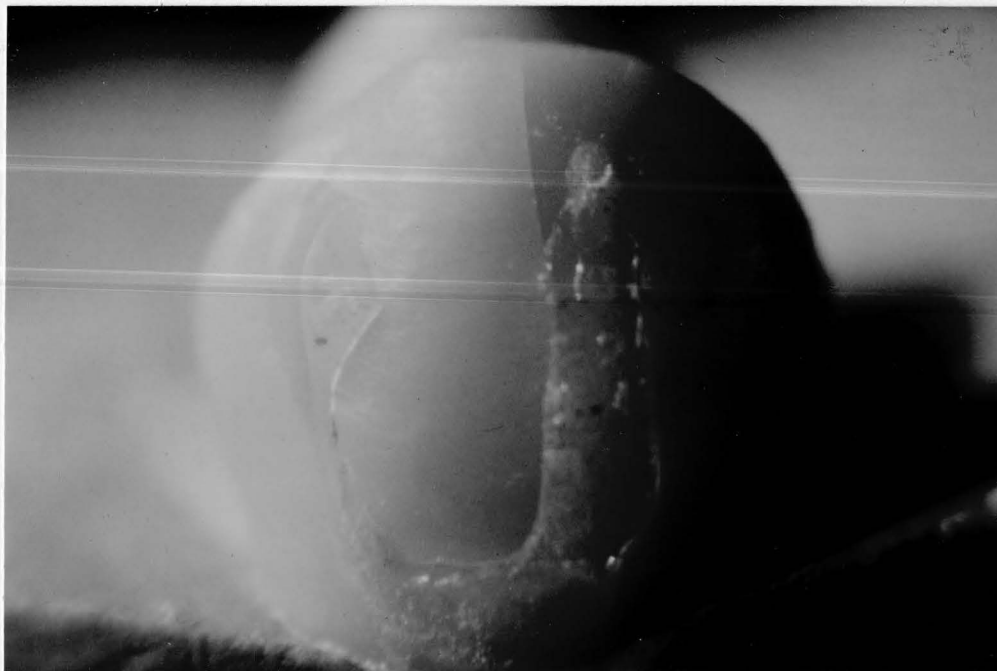


Figure 29. Endur enamel adhesive failure (4X magnification).



Figure 30. Concise combination adhesive failure (4X magnification).

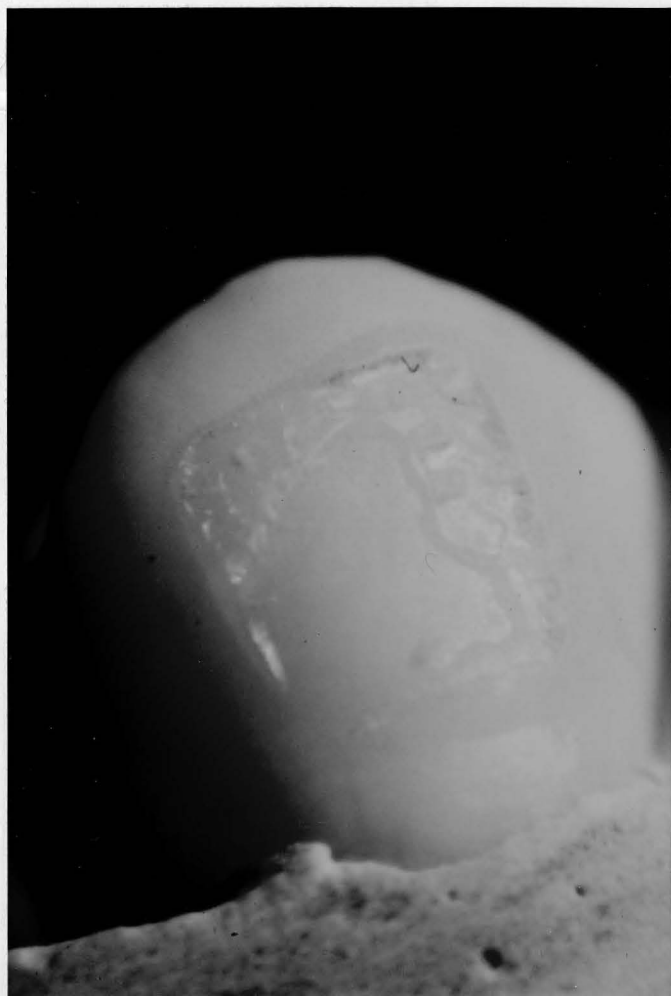


Figure 31. Dyna Bond combination adhesive failure (4X magnification).



## CHAPTER V.

## DISCUSSION

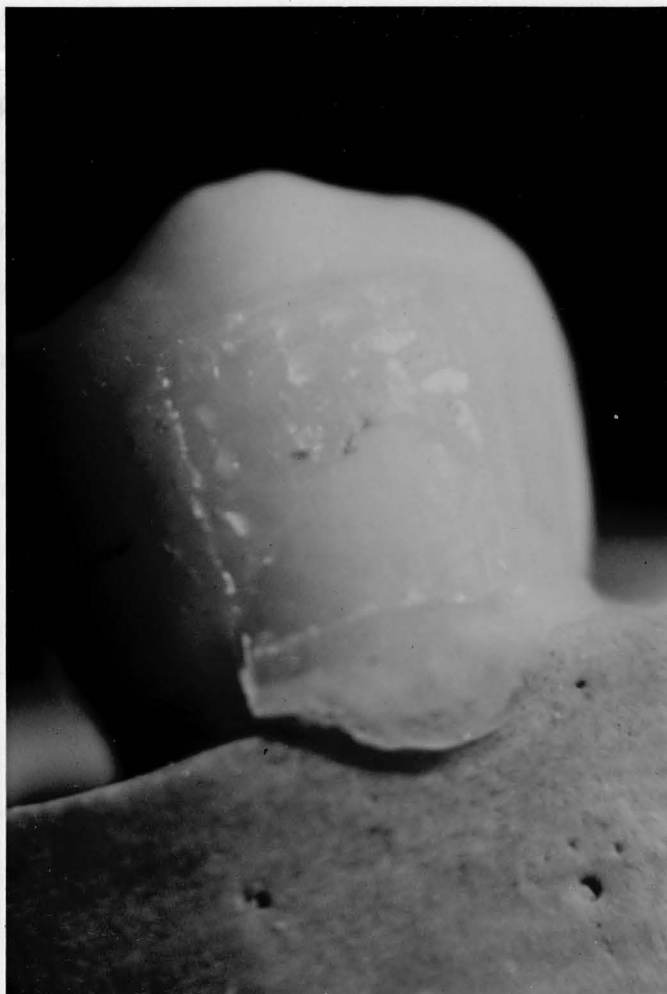


Figure 32. Endur combination adhesive failure (4X magnification).



## CHAPTER V.

### DISCUSSION

The purpose of this investigation was to compare Concise, Dyna Bond, and Endur, and to determine whether there were any differences between these materials. The shear bond strength test was performed by measuring the bond strength of a composite at the bracket - resin - enamel interface.

The experimental design involved the fixation of the tooth bracket sample to the lower jaw of the Instron machine, while a harness was attached to the upper jaw of the machine. The shearing action was then created by placing the tooth bracket sample in a predetermined position and upward movement of the upper jaw of the Instron.

The treatment time of an orthodontic case takes an average of two years. Consequently, a longer testing time may more accurately reflect the behavior of the composite as it may possibly deteriorate with age.

It was interesting from a clinical standpoint to compare Dyna Bond and Endur to Concise. Concise is a composite now well known and popular with a considerable

number of clinicians. Its properties and characteristics were studied by many investigators such as Mitchem and Turner (1974), Silverstone (1975) Zachrisson (1975, 1976) and Moin and Dogon (1977, 1978). All the investigators agreed that Concise presented high qualities and great flexibility for orthodontic usage.

### STATISTICAL DESIGN

The mean shear strengths of these three composites were compared and the results were shown in Table III. No statistical difference between the mean shear strength of Concise, Dyna Bond and Endur was demonstrated on the first day. The same was true for the mean shear strength of Concise and Dyna Bond at the 27th day. However, the mean shear strength of Endur statistically was proven to be weaker when compared to Concise and Dyna Bond on the 27th day.

Hence, after one day, all the three composites were comparable to each other; after 27 days, only Concise and Dyna Bond were comparable; and Endur was weaker than Concise and Dyna Bond.

The differences between the composites could be attributed to several factors: humidity, time factor (polymerization time), difference in the contour of the bracket-base, chemical properties of the material, viscosity of the resins, size of the fillers, pattern of acid etching,

and difference in the tooth sample. All the differences will be discussed in this Chapter, but it should be kept in mind that some of these factors were interrelated.

The presence of humidity could have affected all the composite resins, especially Endur. However, when the physical properties of these three systems were examined closer, the humidity hypothesis did not seem possible. Concise, Dyna Bond, and Endur were all Bis-GMA resin. The physical properties would then be closely similar to each other. In addition, Phillips (1973b) stated that composites showed clinically insignificant water sorption, a low polymerization shrinkage and short working and setting time. With the above reasonings, humidity could not have affected the bonding strength of the resins after the initial 30 minutes.

The role of the time factor appeared to have some credible effects on bonding strength. Table III showed the mean shear strength of Concise increased between the first and the 27th day at the five per cent level of significance. However, there was no increase at one per cent level of significance. On the other hand, the mean shear strength of Dyna Bond showed a significant increase during the same period at both the five per cent and one per cent level of significance. Endur neither increased nor decreased in strength between the two testing periods.

At five per cent level of significance, the effect

of the time factor was significant for both Concise and Dyna Bond. At one per cent level of significance, only Dyna Bond showed an increase in shear strength. Due to the difference in the levels of significance, Concise was shown to be less affected by the time factor than Dyna Bond.

It was evident that there was some change between the first and second testing period. The answer appeared to be the time factor for polymerization. With the present data, complete polymerization appeared to take place somewhere between the first and the 27th day for Concise and Dyna Bond, while Endur took place somewhere within the first day. Concise's polymerization exhibited less change than Dyna Bond, as demonstrated in the different levels of significance.

Since there were two basic brackets used in testing the composite resins, it was interesting to compare the differential behaviors of the upper and lower bicuspid. The comparisons of bonding failures, shown in Tables IV, V, VI, VII, VIII, and IX, were attempted to find correlation in tooth morphology, the type of composite failure, and the brackets used.

Table VI and VII did not show any statistical differences in the mean shear strength of the upper and lower bicuspid, from the first to the 27th day for either Concise or Endur. On the contrary, Tables VIII and IX showed the upper and lower bicuspid of Dyna Bond had a

different behavior. After the first day, the mean shear strength of the upper bicuspid was comparable to the lower bicuspid ( $p > 0.05$ ). The same was true at the 27th day ( $p > 0.05$ ). However, the mean shear strength of the upper bicuspid increased from the first to the 27th day ( $p < 0.01$ ), while the lower bicuspid did not exhibit any changes ( $p > 0.05$ ).

One of the differences in the behavior of the three bonding systems could be attributed to the difference in the adaptation of the bracket base to the tooth surface. Although the manufacturer fabricated a specific design for the bracket base of the upper and lower bicuspid, variability on each tooth surface made perfect adaptation impossible between the upper and lower bicuspid. Greater variation appeared on the upper bracket base compared to the lower. And as previously stated, no attempt was made to recontour the bracket base to the tooth surface. Consequently, the bracket - resin - enamel interface was thicker for the upper bicuspid than for the lower ones. The thickness of the adhesive layer is an important factor in obtaining and maintaining adhesion (Buonocore 1963, Retief 1970a). As the adhesive increases in thickness, the bond strength decreases. Buonocore (1963) and Retief (1970a) proposed a number of explanations: a thin layer may produce fewer imperfections in the interface; a thick layer may deform and fracture readily; and a thin layer will

produce less shrinkage during polymerization.

The upper bicuspid brackets had a thicker bond compared to the lower. For a resin that took a longer time to set, any increase in the bonding material would produce a concomitantly longer polymerization time. Table VI and VII showed no difference in upper and lower bicupids among Concise and Endur. Dyna Bond was the only material that showed increased bond strength from the first to the 27th day for the upper bicuspid brackets ( $p < 0.01$ ). It was previously stated that Dyna Bond was suspected of having a longer setting time. The increase in the resin added to the increase polymerization time. Hence, this explained the increase in strength of the upper bicuspid brackets from the first to the 27th day. Once polymerization stopped, the shearing strength became comparable between a thin and thick bond, provided the thickness of the resin was within limit (Table V).

All the three composites exhibited the three different types of failure, i.e., enamel failure; bracket failure, and combination failure. When an enamel adhesive failure occurred, the composite was then interpreted to have a low affinity for enamel, and a high affinity for the bracket. The opposite was true for a bracket adhesive failure. In the combination failure, since equal amount of the composite was left on both the enamel and bracket, the adhesive had neither a strong nor weak affinity for both

surfaces.

Table X showed Endur and Dyna Bond to have a strong bond to the enamel. This was reflected on the low enamel failure of 13.89% and 5.71% for both materials respectively. Concise had the reverse characteristic. It showed 48.57% enamel failure, and 34.29% bracket failure. Therefore, Concise had a weaker bond to enamel.

Another step in the analysis of the data was to determine correlation between the type of adhesive failure and the mean shear strength. Table XI did not show any correlation ( $p > 0.05$ ). None the less, it can be stated that Concise had the best adhesion to the bracket, while both Endur and Dyna Bond had better adhesion to the enamel. Since Endur had the weakest shear strength, Dyna Bond exhibited better adhesion to enamel than Endur.

No chemical bonding took place between the metal bracket and adhesive. The adhesive occurred as a mechanical lock between the mesh base and the adhesive. Reynolds and Fraunhofer (1976a) claimed that metal attachment required mesh gauze possessing a wire diameter of not less than 150 microns, and that standard mesh number should be 50 or 60 (British standard size). The Unitek bracket mesh base was made of 40 wires per linear inch, with wire size of 10-11 microns in diameter. Moreover, at the point of welding the mesh to the base, the wires were squashed. So it is possible that the bonding to the mesh may be improved by

using different types of bracket mesh base.

#### MATERIAL EVALUATION AND STEREOSCOPIC MICROSCOPE:

Schmohl (1974) and Retief (1975) described two types of composite failure. These were: adhesive and cohesive failures. Cohesive combination failure was described as failure within the composite itself. The results of this investigation showed the failure to be the adhesive type. This was further classified into three sub-groups: adhesive enamel, adhesive bracket and adhesive combination (Ill. 3).

In this investigation it was extremely difficult to make any differentiation between a complete adhesive failure at the enamel or at the mesh base bracket and a true cohesive failure, even when the samples were viewed at 40X magnification.

Schmohl (1974) stated that when the samples were viewed under stereoscopic microscope, the observation revealed a clean fracture between enamel and resin. However, when the same samples were examined with a S.E.M., it revealed evidence of strong micro-mechanical interlocking at the interface.

The above was also supported by Retief (1975), and Moser et al. (1979), that failure at the interface cannot be regarded as a clean interfacial break. Spicules of adhesive, which had penetrated the etched enamel surface during the bonding, fractured during the tensile test and



remained embedded in the enamel surface (Ill. 2).

Since the design of this experiment used stereoscopic microscope, the magnification of the microscope was inadequate in differentiating the pattern of etching between the three etching solutions. At the same token, this investigation could not confirm the statements of previous researchers who claimed that the characteristics of the etched surface were related to acid concentration, ph of the acid, and etching time (Newman 1973 and Silverstone 1974).

The power of microscopic magnification and control of lightning source also presented a problem in the examination for voids at the interface. The number and sites of the voids were suspected to affect the bonding strength. When viewed under the microscope, the ultra thin film of composite appeared very translucent, thus making the detection of voids within the ultra thin surface of composite covering on the mesh pad or enamel, nearly impossible. Attempts to stain the enamel surface with both eosine and alizarine red still failed to produce a good field for examination.

To adequately perform a microscopic evaluation, it would be necessary to use a magnification higher then 40X. Present technology shows the S.E.M. as the most appropriate tool for this purpose.

GENERAL CONSIDERATIONS:

Total control of the tooth sample was not possible in this study. The teeth were contributed from Oral Surgeons of the Greater Chicago area. No attempt was made to identify age, race, sex, habits, and oral hygiene of the patients. Lee, et al. (1972) claimed that unidentified trace elements (e.g. fluoride) may play a role in adhesion. These elements may vary in proportions from patient to patient. Efforts were made to use bicuspid teeth extracted for orthodontic purpose. Most patients undergoing orthodontic treatment belong to a certain age group. Thus, the maturity of the enamel would be at the same level. However, the large sample size masked, in part, some of the biases inherent in this experimental design. Bicuspid teeth were used because they were the teeth most available in sufficient number.

The shear mode for determining bond strength was selected because it was the belief this mode of loading simulated closely the masticatory forces exerted on the brackets.

The manufacturers' instructions for each bonding system were followed accordingly with one exception. The base of the bracket was not contoured to the buccal surface of the tooth. This was considered to be a difficult procedure and the accuracy of the adaptation could not be properly judged. Alteration of the bracket base would

introduce an additional variable into the experimental design.

The excess of the adhesive at the periphery of the bonded brackets varied for each specimen. The removal of such excess could have introduced some alteration in the bond, thus adding another variable into the design. For this reason, no attempt was made to remove this excess adhesive. Rather an attempt was made to control the amount of adhesive placed on the mesh base.

In vitro, simulation of the oral environment can only be average in the best conditions. The design of this investigation did not try to reproduce the pH of the saliva, thermal fluctuations, or bacterial influence nor the various forces in the oral cavity.

Newman (1965) stated that a load of 10 pounds or 200 p.s.i. was probably the maximal clinical orthodontic load. Although Concise and Dyna Bond exhibited bonding strength greater than 10 pounds, this should not necessarily lead to the conclusion that the two materials were the ideal composite resins. Different conditions, some still unknown, may have generated forces far exceeding the present capacity of these two resins.

The high standard deviation in the direct bonding adhesive could be due to several reasons: 1) minor malalignment of the testing apparatus; 2) uneven thickness of adhesive; 3) uneven proportions of the mixed resin

materials; 4) presence of voids within the resins; 5) different viscosity of the three composites. Lower viscosity allowed the material to readily flow over the surface of the enamel, taking advantage of the increased surface area produced by acid conditioning. Dogon (1975) showed that specimens coated with resins of 320 centipoises demonstrated markedly increased tag length, which almost filled the entire space within the etched enamel. This was more noticeable in the resins of relatively low viscosity (236 and 185 centipoises). Therefore, in order to effectively utilize the increased surface area and maximize bond strength, it is necessary to completely fill all the interstices. The viscosity is subjected to the variation in the concentration of the fillers into the matrix of the resin. This concentration in hard and soft particles determine the properties of the composite and its ability to flow over the etched enamel; 6) an uneven etching pattern of the enamel surface. It had been reported that resin showed differences in penetration, depending upon the type of acid used, its strength (pH and percentage), and the time of application. Concise and Dyna Bond used an etching solution containing 37% of orthophosphoric acid, whereas Endur used a 50% orthophosphoric acid. The most consistently uniform and suitable etch was obtained by application of a 37% unbuffered orthophosphoric acid solution applied for 60 seconds (Newman 1973, Silverstone

1974). Moreover, Gwinnett and Matsui (1967) and Brännström and Nordenvall (1977) showed that tag lengths varied from one tooth to another and from one site to another within the same experimental area. Consequently, etching played an important role in bonding.

## CHAPTER VI.

### SUMMARY AND CONCLUSION

The purpose of this study was to compare the shear loading of Concise, Dyna Bond and Endur. For this investigation, 108 upper or lower bicuspid extracted for orthodontic purpose were used and randomly divided into six groups of 18 teeth each. The teeth were stored in a 100% humid environment at 37 degrees C. during the entire experiment. The samples were tested for shear bond strength in a tensile mode by an Instron Universal Testing Machine, at the first and 27th day after bonding. The teeth were placed in a stone mold designed to insure a vertical alignment to the pull of the Instron machine. Using a special stainless steel harness, the shearing mode was executed by a vertical motion, parallel to the bracket-resin-enamel interface. The machine was set at 0.05 inch per minute and a load cell of 100 pounds was used.

The samples were viewed under 40X magnification with a stereoscopic microscope. Three types of adhesive failures were observed: adhesive enamel failure, adhesive bracket failure, adhesive combination failure. No cohesive failures could be observed.

The statistical design used Completely Randomized Design Tests, Duncan's Tests and Chi-Square Tests.

The humidity did not alter the shear bond strength of Concise, Dyna Bond, or Endur.

Endur presented a faster setting time followed by Concise and Dyna Bond.

After 27 days the mean shear strength of Concise and Dyna Bond were comparable. Endur showed the weakest bond strength.

The upper and lower bicuspid exhibited a comparable bond after 27 days.

Concise exhibited the best adhesion to the bracket.

Dyna Bond and Endur showed better adhesion to the enamel. Dyna Bond exhibited a stronger bond to the enamel than Endur.

Future researchers should try to obtain better control in: 1) the origin and dental history of the tooth samples; 2) the contour of the base of the bracket to the tooth surface; 3) using mesh base bracket with mesh gauze between fifty and sixty; 4) the pattern of etching of each tooth; 5) using a S.E.M. to get better investigation on the bonding adhesion.

In addition, the manufacturers should improve the bonding of Concise to enamel, and the bonding of Dyna Bond and Endur to the bracket.

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## APPENDIX A

## APPENDIX A

TECHNICAL SPECIFICATIONS OF THE BRACKETS  
USED IN THIS INVESTIGATION

	UPPER BICUSPID	LOWER BICUSPID
Part No.	019 421 mini base	019 423 mini base
<u>Base Geometry</u>		
Mesial/Distal Width (in)	0.146	0.150
Occlusal/Gingival Height (in)	0.153	0.156
Area (in <sup>2</sup> )	0.0221	0.0221
Mesial/Distal Radius (in)	0.140	0.180
Occlusal/Gingival Radius (in)	0.325	0.470
<u>Base Construction</u>		
Mesh	40 x 40	40 x 40
Wire Diameter	0.010-0.011	0.010-0.011
Calendered	0.008	0.008
Foil Thickness	0.005	0.005
Pore Size	0.012 x 0.012	0.012 x 0.012
<u>Method of Attachment</u>		
% Mesh Damaged by Welding	2.4	0

Stainless steel mesh-base bracket, standard type.

Torque	0 Degree	0 Degree
Angulation	0 Degree	0 Degree
Offset	0 Degree	0 Degree
Slot (in)	.022 x .028	.022 x .028

According to comparison chart established by  
Unitek, 8/27/1979.

## APPENDIX B

## APPENDIX B

MANUFACTURER'S SUGGESTED USE OF CONCISE  
ORTHODONTIC BONDING SYSTEM

Ref. No. 1960

- \* Source: Instructions supplied with kit by the  
manufacturer

## System components:

Each kit contains:

- Two Enamel Bond Sealing Resins: Resin A and Resin B.
- Two Orthodontic Bonding Pastes: Paste A and Paste B. (filled Bis-GMA resins)
- One Etching liquid: 37 per cent orthophosphoric acid. (pH = 1)
- Mixing pads.
- Disposable mixing spatulas.
- Disposable mini-sponge applicators.

## \*Tooth surface preparation:

A. Cleansing:

- Prophylax the teeth thoroughly with pumice and water.
- Rinse with water.

- Air dry.

B. Etching:

- Apply etching liquid to enamel surface for 60 seconds with a mini-sponge applicator, using a dabbling action.
- Rinse thoroughly with oil-free water.
- Dry with air.

\* Sealant application:

- Dispense equal amounts (1-2 drops) of resin A and resin B onto a mixing pad.
- Mix the two resins thoroughly for 5-10 seconds.
- Apply the mixed resins to the etched surface in a thin coat with the sponge applicator.

\* Adhesive preparation:

It is not necessary to wait for this coating to set before proceeding to the adhesive preparation, although the procedure is not changed if the coating polymerizes.

- Place equal portions of Paste A and Paste B on the mixing pad.
- Spatulate the two pastes vigorously for 20 seconds.
- Apply adhesive mix to the bonding bracket.
- Place on tooth and seat it firmly.
- Allow 10 minutes after bonding, before placing arch wire.

- Shelf life at room temperature is one year.  
Unopened kits should be refrigerated (40 degrees F. - 4 degrees C.) to extend shelf life.
- Working time is 1 minute 45 seconds for both sealant and adhesive, at 72 degrees F. (22 degrees C.) and at ratio by volume of 1/1.
- Setting time from start of mix is, for a ratio of 1/1, 2 minutes 30 seconds.
- Working and setting time can be changed by modifying the temperature and the ratio by volume of the pastes.
- One mix was used for one tooth.
- Lot numbers:

. Resin A	9212 SI	}	Kit number 090879
. Resin B	9155 SI		
. Etching liquid	91761		
. Paste A	9501		
. Paste B	9501		
- Compressive strength: after 24 hours in water at 37 degrees C. = 38000 psi
- Tensile strength: after 24 hours in water at 37 degrees C. = 8500 psi
- Coefficient of thermal expansion: at 10-50 degrees C. =  $37 \times 10^{-6}$  Unit x unit per degree C.
- Percentage of water sorption: after one week in water at 37 degrees C. = 0.67 millig./cm<sup>2</sup>.



## APPENDIX C

## APPENDIX C

## MANUFACTURER'S SUGGESTED USE OF DYNA-BOND

- \* Source: Instructions supplied with kit by manufacturer.

Each kit contains:

- One 14 gms. jar of Catalyst adhesive paste.
- One 14 gms. jar of Universal adhesive paste.
- One 7 gms. bottle of Catalyst sealant.
- One 7 gms. bottle of Universal sealant.
- One 15 ml. bottle of etching liquid  
(37% phosphoric acid).
- Pads of mixing slips.
- Double ended spatulas.
- Double ended brush tip insert holders.
- Brush tip inserts.

- \* Tooth surface preparation:

A. Cleansing:

- Prophylax the teeth thoroughly with pumice and water.
- Rinse with water.
- Air-dry.

B. Etching:

- Apply etching liquid to enamel surface for 60

seconds with a cotton pellet. Dab the liquid onto the teeth.

- Rinse with water.
- Dry with air.

\* Sealant application:

- Dispense equal amounts (1 or 2 drops) of Catalyst sealant and Universal sealant onto a mixing pad.
- Mix the two resins thoroughly for 10 seconds.
- Apply a thin coat of sealant mixture with a single brush stroke to the etched enamel surface.

\* Adhesive preparation:

Adhesive preparation and bracket placement should begin immediately after all bonding surfaces are covered with sealant.

- Place a small amount of Catalyst adhesive and of Universal adhesive on a mixing pad.
- Spatulate the two pastes vigorously for 20 seconds.
- Apply adhesive mix to the bonding bracket.
- Place on tooth and seal it firmly.
- Allow 10 minutes after bonding, before placing arch wire.

Notes:

- Shelf life of one year at 20-22 degrees C. (68-72 degrees F.)
- Working time for both sealant and adhesive is 2 mn.
- Setting time is 3 minutes for the sealant.

- Setting time is 4 minutes 30 seconds for the adhesive.
- One mix was used for one tooth.
- Lot numbers:
  - . Catalyst sealant 061 879
  - . Universal sealant 061 879
  - . Etching liquid 083 079
  - . Catalyst adhesive 081 779
  - . Universal adhesive 081 779
- Compressive strength:
- Tensile strength:
- Coefficient of thermal expansion:
- Percentage of water sorption:  $1,47 \text{ mg./cm}^2$
- Bis - GMA filled resin: 50/50% hard and soft filler.

## APPENDIX D

## APPENDIX D

MANUFACTURER'S SUGGESTED USE OF ENDUR  
(Combination Kit)

- \* Source: Instructions supplied with kit. Endur is an auto-polymerizing dimethacrylate system.

Each kit contains:

- One 15 gms. jar of adhesive catalyst, a viscous paste.
- One 15 gms. jar of adhesive resin, a viscous paste.
- One 8 gms. jar of adhesive resin, fast set.
- One 7.5 gms. bottle of sealant resin of low viscosity.
- One 7.5 gms. bottle of sealant catalyst of low viscosity.
- One 15 gms. bottle of etching solution (50% phosphoric acid).
- Pads of mixing bracket tray.
- Double ended spatulas.
- Applicator brushes.

\*Tooth surface preparation:

A. Cleansing:

- Prophylax the teeth thoroughly with pumice and water.
- Rinse with water.
- Dry the teeth with the air syringe.

B. Etching:

- Apply the Endur etching solution with a cotton pellet or fine brush to enamel surface for 60 to 90 seconds. Gently dab the etching solution.
- Rinse thoroughly with a forceful air-water spray.
- Dry the etched enamel with clean, dry air.

\* Sealant application:

- Dispense one drop of Endur sealant resin and one drop of Endur sealant catalyst into the same mixing cavity on the mixing-bracket tray.
- Gently stir the sealant mixture with the applicator brush (2-3 stirs are adequate).
- Immediately apply the mixed sealant. A single thin coat is all that is necessary. The sealant will polymerize in situ within three minutes.

\*Adhesive preparation:

Bracket and adhesive placement can begin immediately after sealant application or within a reasonable time period. Chemical bonding between bracket adhesive and sealant will occur independent of sealant polymerization time.

- Dispense approximately equal portions of Endur adhesive resin and adhesive catalyst.
- Mix together for approximately 5 to 10 seconds.  
A vigorous spatulation is undesirable.
- Wipe the bracket through the mixed adhesive.
- Position the bracket on the sealed tooth and press firmly and hold for several seconds.
- Allow approximately 15 minutes after bonding before placing arch wire.

Notes:

- Shelf life of approximately six months when stored at room temperature. However these materials kept refrigerated get additional shelf life.
- Working time of Endur adhesive is 2 minutes at 68-72 degrees F. At 40 degrees F. the working time will be approximately four minutes.
- Setting time of the adhesive at mouth temperature is 3 to 3 1/2 minutes. Bond strengths will continue to increase for 24 hours.
- Setting time of Endur sealant after application to teeth will be approximately 3 minutes.
- One mix was used for one tooth.
- Lot numbers:
  - . Sealant catalyst      9 A060



. Sealant resin	9 A050	} Lot No. 9 F080
. Etching solution	9 D070	
. Adhesive catalyst	H 0059	
. Adhesive resin	H 0060	

## APPENDIX E

## APPENDIX E

Raw shear strength of the Concise group measured after one day (expressed in pounds).

SAMPLES	TOOTH TYPE	SHEAR VALUE	FAILURE TYPE
1	U	---	Fracture
2	U	9.30	E
3	U	17.50	B
4	U	11.40	E
5	U	10.50	B
6	U	11.05	E
7	L	11.20	B
8	U	12.80	E
9	L	16	C
10	U	10	C
11	U	10.6	E
12	U	16.6	E
13	U	15.8	C
14	U	17.5	C
15	U	13.7	B
16	L	14.42	B
17	L	11.40	C
18	L	10.81	B

$$\begin{aligned}\Sigma X &= 220.58 \\ \bar{X} &= 12.98 \\ \text{S.D.} &= 2.93\end{aligned}$$

U = upper bicuspid  
L = lower bicuspid

E = enamel failure  
B = bracket failure  
C = combination failure

## APPENDIX F

## APPENDIX F

Raw shear strength of the Endur group measured after one day (expressed in pounds).

SAMPLES	TOOTH TYPE	SHEAR VALUE	FAILURE TYPE
19	L	8.82	B
20	L	10.90	B
21	L	10.02	B
22	L	10	B
23	L	14.40	B
24	L	11.96	B
25	L	8	B
26	U	9.18	B
27	L	11.61	B
28	U	11.9	B
29	U	13.8	B
30	U	13.76	E
31	U	11.68	B
32	U	10	B
33	U	8.24	B
34	L	8.96	C
35	L	11.96	B
36	U	9.52	B

$$\begin{aligned}\Sigma X &= 194.71 \\ \bar{X} &= 10.82 \\ S.D. &= 1.94\end{aligned}$$

U = upper bicuspid

L = lower bicuspid

E = enamel failure

B = bracket failure

C = combination failure

## APPENDIX G

## APPENDIX G

Raw shear strength of the Dyna Bond group measured after one day (expressed in pounds).

SAMPLES	TOOTH TYPE	SHEAR VALUE	FAILURE TYPE
37	U	6	C
38	U	5.40	C
39	U	4.6	E
40	L	7.3	B
41	L	4.48	C
42	L	5.90	B
43	L	10.80	B
44	L	16.40	B
45	L	18	B
46	L	15.76	B
47	L	12.80	E
48	L	14.98	B
49	L	14.40	C
50	U	12.56	B
51	U	15.28	C
52	L	12.5	B
53	U	10.48	E
54	L	9.60	E

$$\begin{aligned}\Sigma X &= 197.24 \\ \bar{X} &= 10.96 \\ S.D. &= 4.45\end{aligned}$$

U = upper bicuspid

L = lower bicuspid

E = enamel failure

B = bracket failure

C = combination failure

## APPENDIX H



## APPENDIX H

Raw shear strength of the Endur group measured after 27 days (expressed in pounds).

SAMPLES	TOOTH TYPE	SHEAR VALUE	FAILURE TYPE
55	U	--	Fracture
56	L	10.36	B
57	L	10.62	B
58	U	11.70	B
59	L	8.81	C
60	L	13.90	C
61	L	13	B
62	U	8.84	C
63	L	13.28	B
64	U	10.50	B
65	U	12.84	B
66	L	13.80	B
67	L	8.20	B
68	U	9.24	B
69	U	11.80	B
70	U	10.10	B
71	L	12.20	B
72	U	5.60	E

$$\begin{aligned}\Sigma X &= 184.79 \\ \bar{X} &= 10.87 \\ \text{S.D.} &= 2.26\end{aligned}$$

U = upper bicuspid

L = lower bicuspid

E = enamel failure

B = bracket failure

C = combination failure

## APPENDIX I

## APPENDIX I

Raw shear strength of the Concise group measured after 27 days (expressed in pounds).

SAMPLES	TOOTH TYPE	SHEAR VALUE	FAILURE TYPE
73	L	14.7	E
74	U	11.02	B
75	L	14.40	E
76	L	14.24	B
77	L	15.80	C
78	L	12.30	E
79	U	13.40	E
80	U	18.70	B
81	U	12.30	B
82	L	24.40	E
83	U	17.58	E
84	L	14.88	E
85	U	17.6	B
86	L	15	E
87	L	16	E
88	L	15.20	E
89	L	12.76	E
90	U	14.80	B

$$\begin{aligned}\Sigma X &= 275.08 \\ \bar{X} &= 15.28 \\ \text{S.D.} &= 3.01\end{aligned}$$

U = upper bicuspid  
L = lower bicuspid

E = enamel failure  
B = bracket failure  
C = combination failure

## APPENDIX J

## APPENDIX J

Raw shear strength of the Dyna Bond group measured after 27 days (expressed in pounds).

SAMPLES	TOOTH TYPE	SHEAR VALUE	FAILURE TYPE
91	L	22.25	B
92	U	18	B
93	U	16.6	B
94	U	12.9	C
95	U	11.9	B
96	U	13.7	B
97	L	12.84	B
98	L	14.60	B
99	U	16.60	B
100	U	14.72	B
101	L	16.50	B
102	U	15.10	B
103	L	9.70	B
104	L	17.90	E
105	U	19.76	B
106	U	17.60	B
107	U	22.20	B
108	U	22.20	B

$$\begin{aligned}\Sigma X &= 295.07 \\ \bar{X} &= 16.39 \\ \text{S.D.} &= 3.63\end{aligned}$$

U = upper bicuspid

L = lower bicuspid

E = enamel failure

B = bracket failure

C = combination failure

## APPENDIX K

## APPENDIX K

Raw shear strength of upper bicuspid measured at the 1st and 27th day (expressed in pounds).

OBSERVATION	Group A 1st DAY	Group B 27th DAY
1	9.30	11.02
2	17.50	13.4
3	11.4	18.7
4	10.5	12.3
5	11.05	17.58
6	12.08	17.6
7	10	14.8
8	10.6	18
9	16.6	16.6
10	15.8	12.9
11	17.5	11.9
12	13.7	13.7
13	6	16.6
14	5.40	14.72
15	4.6	15.10
16	12.56	19.76
17	15.28	17.6
18	10.48	22.2
19	9.18	22.2
20	11.9	11.7
21	13.8	8.84
22	13.76	10.50
23	11.68	12.84
24	10	9.24
25	8.24	11.80
26	9.52	10.10
27	--	5.60

$\Sigma X = 298.43$   
 $\bar{X} = 11.48$

$\Sigma X = 387.30$   
 $\bar{X} = 14.34$

## APPENDIX L



## APPENDIX L

Raw shear strength of lower bicuspid measured at the 1st and 27th day (expressed in pounds).

OBSERVATION	Group A 1st DAY	Group B 27th DAY
1	11.2	14.7
2	16	14.4
3	14.42	14.24
4	11.4	15.8
5	10.81	12.3
6	7.3	24.4
7	4.48	14.88
8	5.9	15
9	10.8	16
10	16.4	15.20
11	18	12.76
12	15.76	22.25
13	12.8	12.84
14	14.98	14.6
15	14.4	16.5
16	12.5	17.9
17	9.6	9.7
18	8.82	10.36
19	10.9	10.62
20	10.02	8.81
21	10	13.9
22	14.4	13
23	11.96	13.28
24	8	13.80
25	11.61	8.20
26	9.96	12.2
27	11.96	--
	$\Sigma X = 313.38$ $\bar{X} = 11.61$	$\Sigma X = 357.64$ $\bar{X} = 13.76$

## APPENDIX M

## APPENDIX M

Shear strength of the upper and lower bicuspid  
tested at the first and 27th day (expressed in pounds).

U 1	U 27	L 1	L 27
9.18	11.7	8.82	10.36
11.9	8.8	10.90	10.62
13.8	10.50	10.02	8.81
13.76	12.84	10	13.90
11.68	9.24	14.4	13
10	11.8	11.96	13.28
8.24	10.10	8	13.80
9.52	5.60	11.61	8.20
		8.96	12.20
		11.96	
$\Sigma X = 88.08$	$\Sigma X = 80.62$	$\Sigma X = 106.63$	$\Sigma X = 104.17$
$\bar{X} = 11.01$	$\bar{X} = 10.07$	$\bar{X} = 10.66$	$\bar{X} = 11.57$
SD = 2.10	SD = 2.26	SD = 1.90	SD = 2.15

U 1 = Upper bicuspid tested at 1st day  
 U 27 = Upper bicuspid tested at 27th day  
 L 1 = Lower bicuspid tested at 1st day  
 L 27 = Lower bicuspid tested at 27th day

## APPENDIX N

## APPENDIX N

Concise shear strength of upper and lower bicuspid tested at the first and 27th day (expressed in pounds).

U 1	U 27	L 1	L 27
9.30	11.02	11.20	14.7
17.50	13.40	16	14.4
11.4	18.70	14.42	14.24
10.5	12.30	11.40	15.80
11.05	17.58	10.81	12.30
12.8	17.6		24.40
10	14.8		14.88
10.6			15
16.6			16
15.8			15.20
17.5			12.76
13.7			
$\Sigma X = 156.75$	$\Sigma X = 105.4$	$\Sigma X = 63.83$	$\Sigma X = 159.68$
$\bar{X} = 13.06$	$\bar{X} = 15.06$	$\bar{X} = 12.77$	$\bar{X} = 14.52$
SD= 3.06	SD= 2.97	SD = 2.31	SD = 4.25

U 1 = Upper bicuspid tested after 1st day  
 U 27 = Upper bicuspid tested at 27th day  
 L 1 = Lower bicuspid tested at 1st day  
 L 27 = Lower bicuspid tested at 27th day

## APPENDIX O

Dyna Bond shear bond strength of upper and lower bicuspid tested at the first and 27th day (expressed in pounds).

U 1	U 27	L 1	L 27
6	18	7.3	22.25
5.4	16.6	4.48	12.84
4.6	12.9	5.9	14.6
12.56	11.9	10.8	16.5
15.28	13.7	16.4	9.7
10.48	16.6	18	17.9
	14.72	15.76	
	15.10	12.80	
	19.76	14.98	
	17.6	14.40	
	22.20	12.5	
	22.20	9.60	
$\Sigma X = 54.32$	$\Sigma X = 201.28$	$\Sigma X = 142.92$	$\Sigma X = 93.79$
$\bar{X} = 9.05$	$\bar{X} = 16.77$	$\bar{X} = 11.91$	$\bar{X} = 15.63$
SD = 4.37	SD = 3.37	SD = 4.35	SD = 4.33

U 1 = Upper bicuspid tested 1st day after bonding  
 U 27 = Upper bicuspid tested 27th day after bonding  
 L 1 = Lower bicuspid tested 1st day after bonding  
 L 27 = Lower bicuspid tested 27th day after bonding

## APPENDIX P



## APPENDIX P

Concise shear strength according to the type of failure after one day (expressed in pounds).

ENAMEL	BRACKET	COMBINATION
9.30	17.50	16
11.40	10.50	10
11.05	11.20	15.8
12.80	12.70	17.5
10.6	14.42	11.4
16.6	10.81	
$\Sigma X = 61.75$	$\Sigma X = 77.13$	$\Sigma X = 70.7$
$\bar{X} = 10.29$	$\bar{X} = 12.86$	$\bar{X} = 14.14$
SD = 2.14	SD = 2.70	SD = 3.25

## APPENDIX Q

## APPENDIX Q

Concise shear strength according to the type of failure after 27 days (expressed in pounds).

ENAMEL	BRACKET	COMBINATION
14.7	11.02	15.80
14.4	14.24	
12.3	18.70	
13.4	12.30	
24.40	17.6	
17.58	14.8	
14.88		
15		
16		
15.20		
12.76		
$\Sigma X = 170.62$	$\Sigma X = 88.66$	15.80
$\bar{X} = 15.51$	$\bar{X} = 14.78$	
SD = 3.29	SD = 2.96	

## APPENDIX R

## APPENDIX R

Dyna Bond shear strength according to the type of failure after one day (expressed in pounds).

ENAMEL	BRACKET	COMBINATION
4.6	7.3	6
4.48	5.90	5.40
12.80	10.80	14.40
10.48	16.40	15.28
9.60	18	
	15.76	
	14.98	
	12.56	
	12.50	
$\Sigma X = 41.96$	$\Sigma X = 114.20$	$\Sigma X = 41.08$
$\bar{X} = 8.39$	$\bar{X} = 12.69$	$\bar{X} = 10.27$
SD = 3.71	SD = 4.11	SD = 5.29

## APPENDIX S

## APPENDIX S

Dyna Bond shear strength according to the type of failure after 27 days (expressed in pounds).

ENAMEL	BRACKET	COMBINATION
17.90	22.25 18 16.6 11.9 13.7 12.84 14.60 16.60 14.72 16.50 15.10 9.70 19.76 17.60 22.20 22.20	12.9
17.9	$\Sigma X = 264.27$ $\bar{X} = 16.52$ $SD = 3.74$	12.9

## APPENDIX T



## APPENDIX T

Endur shear strength according to the type of failure after one day (expressed in pounds).

ENAMEL	BRACKET	COMBINATION
13.76	8.82 10.90 10.02 10 14.40 11.96 8 9.18 11.61 11.9 13.8 11.68 10 8.24 11.96 9.52	8.96
13.76	$\Sigma X = 171.99$ $\bar{X} = 10.75$ $SD = 1.86$	8.96

## APPENDIX U

## APPENDIX U

Endur shear strength according to the type of failure after 27 days (expressed in pounds).

ENAMEL	BRACKET	COMBINATION
5.60	10.36 10.62 11.70 13 13.28 10.50 12.84 13.80 8.20 9.24 11.80 10.10 12.20	8.81 13.90 8.84
5.60	$\Sigma X = 147.64$ $\bar{X} = 11.36$ $SD = 1.68$	$\Sigma X = 31.55$ $\bar{X} = 10.52$ $SD = 2.93$

## APPROVAL SHEET

The thesis submitted by Paul Alexandre, D.E.D.L., D.F.M.L. has been read and approved by the following committee:

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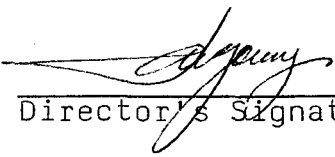
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The final copies have been examined by the director of the thesis and the signature which appears below verifies the fact that any necessary changes have been incorporated and that the thesis is now given final approval by the Committee with reference to content and form.

The thesis is therefore accepted in partial fulfillment of the requirements for the degree of Master of Science.

Date

April 7<sup>th</sup>, 1980

  
Director's Signature